BUCKMASTER'S · EXPERIMENTAL PHYSICS

THE ELEMENTS

OF

EXPERIMENTAL PHYSICS

ACOUSTICS, LIGHT AND HEAT
MAGNETISM AND ELECTRICITY

BY

J. C. BUCKMASTER

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PREFACE

The following elementary work has been written with a desire to facilitate the study of Experimental Science. It is not intended as an elaborate treatise, but as a compact Text-Book.

The principles of Science are now so intimately associated with the arts and occupations of every-day life, that the importance of scientific knowledge, as a part of general education, can no longer be disregarded, and every facility should be given to systematic courses of instruction in Science, either in schools or evening classes, as full and complete as time and opportunity will permit.

The attention of Parliament was directed to this question immediately after the Exhibition of 1851 and recently in the Report of the Royal Commission on Public Schools.

The Science examinations of the Department of Science and Art have led, in four years, to the formation of more than one hundred local classes; and it

is chiefly with a view to the instruction given in these classes that I have been induced to prepare this work. In the arrangement of the subjects I have followed, in all important matters, the syllabus of Professor Tyndall.

For several years I was occupied as a teacher of chemistry and physics in a large Training College, and no one who has had any experience as a teacher of either boys or men can fail to have observed the interest which always attaches to instruction in these subjects.

The death of the late Lord Ashburton, and the retirement of Canon Moseley and Dr. Temple from all official interest in schools aided by the State, has been attended with a decline in Elementary Science as a part of Primary education.

When the natural and experimental sciences take equal rank with the classics in the endowed schools and Universities, the character of our education will be so modified as not only to be a means of mental training, but also adapted to the practical purposes of every-day life. The men who have given us the steam-engine, the railroad, and the telegraph, are under little obligation to a Latin grammar or a Greek Lexicon.

Dr. Faraday, in his evidence before the Royal Commission on Public Schools, says, "I would teach

a boy of eleven years of age, of ordinary intelligence, the elements of all those sciences (acoustics, light, heat, magnetism, electricity, and chemistry) which come before classics in the programme of the London University. With a candle, a lamp, and a lens or two, an intelligent person might teach, in a very short time, the elements of optics; and so with chemistry and the other sciences. In the management of the electric light the Trinity Board have had to remove keeper after keeper from the lighthouses under their direction, because it was difficult to find men of sufficient intelligence to manage the light, arrange a common lamp, or observe those proceedings necessary for its security, or any attempt to make notes of what they ought to observe. Their profound ignorance of the most elementary principles of Science is continually manifest. In France I find an intelligent class of men, able to give a reason, supply any corrections, make careful observations, and act for themselves if necessity require it. I can find no such men here." Sir Charles Lyell, Dr. Carpenter, and others, give similar evidence; but to no one are these truths more evident than to him who has felt the wearisome monotony of ignorant labour.

An Elementary work on Experimental Science can have little claim to originality. In this respect I make no pretensions. I think it right to mention the assist-

ance I have derived from a perusal of the works of Ganot, Müller, and Faraday. If I have produced a book suitable to the requirements of those engaged in teaching or learning Science, I have accomplished my object, and I now leave the work to make its own way.

St. John's Hill, Wandsworth, S. W.,
December, 1864.

THE ELEMENTS

OF

EXPERIMENTAL PHYSICS.

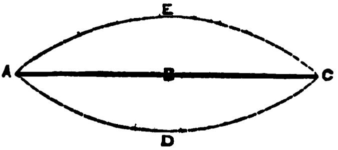
ACOUSTICS.

Acoustics is that branch of physics which treats of the nature of sound, and the laws which relate to its production and propagation.

Sound is caused by the mechanical vibrations of an elastic body, which are transmitted by undulations through the atmosphere to the ear. Every noise or sound is accompanied by some action of this kind. The report of a cannon causes a tremulous motion of the ground for some distance. Sounds of a softer nature, proceeding from musical instruments, such as those of a piano or harp, are all accompanied with a sensible tremor or vibration of the floor. The vibratory body is said to be sonorous, and the body through which the sound is transmitted is called the medium. If a glass tumbler be gently struck with any hard body a tremulous agitation is communicated to the entire mass. The air surrounding the glass is thrown into corresponding undulations, which strike on a delicate membrane stretched across the interior of the ear, called the *tympanum*, or drum of the ear, and in this way the sensation of sound is excited.

Suppose a stretched cord, represented by the line A B C, *Fig.* 1, to be drawn aside to D; in returning to its original position it does so with a momentum

FIG. 1.



which carries it past the line A B C to A E C, from which it returns again *nearly* to A D C, and so backward and forward until, after a number of oscillations, it comes to a state of rest. The space through which the cord oscillates, or the amplitude of the oscillations, diminishes, but the time required for a small oscillation is the same as that required for a large one. The oscillations of sonorous bodies are too rapid to be either seen or counted, but by a simple experiment we can make these manifest to the eye.

Nodal Lines and Points.—Sprinkle some fine dry sand on a plate of thin metal or glass, holding the plate firmly with the hand, or better, with a pair of pincers; then draw a violin bow over one of its edges; the particles of sand will be seen to dance up and down, and finally arrange themselves in curious figures. Now this motion is due to the vibrations of the plate. If we strike a tuning-fork, and then touch the surface of some mercury, the undulations or waves are distinctly visible.

By experiments made by Chaldni the following laws were detected:—

1. Any particular sound always produces the same figure, held in the same position. If the sound be changed, the figure disappears at once and a new one is formed.

2. The gravest sound is accompanied by the simplest figure, and the more acute the sound the more com-

plex the figure; that is, the more nodal lines and points will be produced on the plate.

An undulation may be either stationary or progressive. The points of a wave which never change their position are the nodal points. In a progressive wave an alternate elevation and depression takes place in succession in the several parts of the vibrating body.

The experiments of Savart show that the molecular motions of one body may be communicated to another if there exist any intervening medium, and the more perfect the medium the more perfect the communication.

Moisten a thin membrane and stretch it over the top of a tumbler, secured with a piece of twine; place it in a horizontal position, and, when dry, strew fine sand over the surface; hold a glass plate, covered with fine dry sand, horizontally over the membrane, and set it in vibration by drawing a violin bow over one of its edges, so as to produce the acoustic figures; these figures will be immediately imitated and produced in the sand on the membrane. If the plate be inclined to the plane of the membrane, the figures will change, although the vibrations will remain the same, and, when it becomes perpendicular to the horizon, and therefore to the plane of the membrane, they become changed into a system of straight lines.

Conduction of Sound.—The vibrations of a sonorous body impart to the air in contact with it an undulatory or wave-like motion which spreads outwards in successive spheres. These undulations produce a temporary condensation and rarefaction of the air, and the length of the wave is the distance between the centres of condensation or rarefaction. That the air is necessary for the production of sound is easily proved by the experiment of enclosing a bell within the receiver of an air-pump. As the exhaustion

of the air proceeds the sound of the bell grows fainter and fainter, until at last it nearly dies away. The hammer is seen to strike the bell, but there is no sound, because there is no medium to convey these undulations to the ear. The experiment is never quite successful, owing to the impossibility of obtaining a perfect vacuum, and insulating the bell from the metallic plate of the air-pump. The atmosphere is not the only medium of sound. Other bodies convey it, and some with greater rapidity. If a pistol be fired over a stream of water, where fishes can be seen, the agitation among them shows they have heard the report; and even talking on the bank will disturb them. The sound of a bell rung under water may be heard at a long distance by a person diving. The scratch of a pin may be heard from one end of a piece of timber to the other. Sound is therefore transmitted through wood, metals, water, and other media, but with different velocities. The principle of solids being able to transmit sound has been applied to the construction of THE STETHOSCOPE, which consists of a hollow cylinder of wood like a small trumpet. The wide mouth is applied closely to the chest, and the other is held to the ear. The medical man is thus enabled to hear distinctly the action of the organs of respiration, and judge as to their healthy action. The power of the atmosphere to transmit sound will vary according to its humidity, density, and other circumstances. Anything which disturbs the condition of the atmosphere interferes with the transmission of sound. When the wind blows from the hearer towards the sounding body, the sound often ceases to be heard which would be distinctly audible in a calm. The undulations of sound waves are also obstructed by the falling of rain or snow. In cold, clear weather sound is transmitted to

a greater distance than in warm weather, because the density of the atmosphere is increased by cold and diminished by heat. At night the air is less liable to variations of temperature and the noises of business. Many sounds are distinctly perceptible on a still, calm evening, which would be completely destroyed in the daytime before they reach the ear. On the top of high mountains, where the air is greatly rarefied, the human voice can be heard only for a short distance, and the report of a pistol sounds like a penny cracker; but in a diving-bell, where the air is greatly compressed, a gentle whisper is almost as loud as a shout in the open air.

The intensity of sound, which is usually understood as its loudness, depends on the force with which the vibrating particles of the air strike upon the drum of the ear. The intensity depends on the power of the exciting cause. Sound decreases in intensity from the point where it originates, according to the same law by which the attraction of gravitation varies, viz., *inversely as the square of the distance.*

The sound of a vibrating cord diminishes as the vibrations become smaller and smaller, and when the cord comes to a state of rest, the sound is no longer heard. The intensity of the sound diminishes with the amplitude of the vibrations of the aërial particles, and the length of vibration of the cord determines the length or amplitude of these vibrations of the aërial particles. If two strings of the same thickness and of the same material, but of different lengths, be stretched by the same weight, the rates of vibration are inversely proportional to the length of the string. If two strings of the same length and material, but of different diameters, be stretched by the same weight, the rates of vibration are inversely

proportional to the diameters of the strings. If, for example, one string be three times the diameter of another string, the number of vibrations executed by the string of the greater diameter in one second will be only one-third of the number executed by the string of the lesser diameter. If two strings of the same length, material, and diameter be stretched by different weights, the rates of vibration are proportional to the square root of the stretching force. If one string be stretched by a weight of 9 lbs., and the other by a weight of 16 lbs., the rates of vibration of these strings will be as the square root of 9 is to the square root of 16, or as 3 : 4.

These laws may be expressed briefly as follows :—

1. When the tension and thickness of the string remain the same, the number of vibrations made per second will increase in the same proportion as the length of the string is diminished, and *vice versâ*.

2. The number of vibrations per second will increase in proportion to the square root of the stretching force.

3. The number of vibrations per second is in the inverse proportion of the diameter of the string.

From these laws we obtain the following formula :—

Let n be the number of vibrations per second, l the length of string, s the stretching force, d the diameter of the string—

$$n = a \times \frac{\sqrt{s}}{l\,d}$$

a is the number depending on the quality of the material of the string, and will vary if two different strings be compared, and it follows that $a = \frac{n\,l\,d}{\sqrt{s}}$ by which the value of a is determined.

The velocity of all sound undulations is uniform. The softest whisper passes over in the

same time, under the same conditions, the same space as the loudest thunder. When the temperature is 62° Fahrenheit, sound travels at the rate of 1,120 feet per second, or about thirteen miles per minute; for every variation of a degree in temperature above or below 62°, the velocity either increases or diminishes at the rate of about thirteen inches. M. Biot, however, gives, as the result of his experiments with the thermometer at 32°, 1809·42 feet per second.

Musical Sounds.—The regular and uniform vibrations of sonorous bodies, which are sufficiently rapid, produce agreeable or musical sounds. The difference between a noise and a musical sound is not easy to describe.

In all musical sounds the vibrations of the sonorous body must be exactly alike in duration and intensity, and must recur after equal intervals of time; such vibrations are called *isochronal.*

Noise, however, results from a single impulse communicated irregularly to the ear, or from vibrations of unequal duration. The crack of a whip, the report of firearms, the roar of thunder and the ocean, are simply noises.

The pitch of a musical sound depends on the rapidity of the vibrations. Very rapid vibrations are said to be acute or sharp, whilst those which arise from very slow vibrations are said to be grave.

Musical notes are said to be high or low. The higher note is that which arises from more rapid, and the lower note from slower vibrations. These terms, high or low, acute or grave, are only relative. One sound may be acute with reference to a second sound, while it may be grave with reference to a third. A sound produced by 160 vibrations in a second must be acute or high with reference to one of

80 vibrations, and grave with reference to one of 320 vibrations. A combination of these acute and grave sounds according to harmony constitutes music. The same musical note produced by the same number of vibrations in the flute, clarionet, piano, or the human voice, is in each case different; but why this is we are unable to say. The French call it *timbre*. According to the investigations of M. Savart, the gravest sound was produced by 16 vibrations per second, and the most acute sound by 48,000 vibrations per second. If we take 1,120 feet as the velocity of sound, we find, for the length of the undulations corresponding to the gravest sounds, 68 feet, and for the length of the undulations corresponding to the most acute sounds, about a quarter of an inch. The limit of sounds for music is much less, especially in singing. Savart gives, for the gravest sounds of the male voice, 190 vibrations per second, and for the female voice, 572. For the most acute sounds of the male voice he gives 678 vibrations per second, and for the female voice, 1,606.

A Musical Concord. — Two musical notes sounded at the same time produce an agreeable sound on the ear. When the vibrations which cause these sounds are performed in equal times, they are said to be in unison; and when one note is caused by twice the number of vibrations in a given time which another makes, it is said to be *an octave*. The combination of sounds in unison is called a musical concord or *harmony*, but if the effect be disagreeable it is called a *discord*. From this former combination there may result a series of sounds which constitute what is called a MUSICAL SCALE, in which the sounds recur in the same order, in groups of seven, and each group constitutes a GAMUT, or diatonic scale, because they are steps by which the tone ascends

from any given note to the corresponding note above, produced by vibrations twice as rapid. These notes are distinguished by letters and names:

Do, Re, Mi, Fa, Sol, La, Si, Do^1,
or C, D, E, F, G, A, B, C.

The first six of these names are the first syllables of the first six verses of the hymn that is chanted at Rome on the feast of St. John.

These notes may also be distinguished by numbers, which indicate the length of the strings and the number of vibrations necessary to produce them. If the length of the string producing the primary key-note be 32 inches, the length of the strings to produce the tones in the entire scale are—

Do,	Re,	Mi,	Fa,	Sol,	La,	Si,	Do^1.
32,	30,	27,	24,	21,	20,	18,	16.

Whatever be the number of vibrations per second necessary to produce the first note, Do, and we represent it by unity, then the numbers necessary to produce the other seven notes of the octave will be—

Do,	Re,	Mi,	Fa,	Sol,	La,	Si,	Do^1.
1,	$\frac{9}{8}$,	$\frac{5}{4}$,	$\frac{4}{3}$,	$\frac{3}{2}$,	$\frac{5}{3}$,	$\frac{15}{8}$,	2.

And to whatever length this musical scale be extended, it will still be found a repetition of similar octaves. A column of air vibrating in a pipe obeys the same general law. The shorter the pipe, the higher the note. If the same note be produced on any musical instrument, that note is due to the same number of vibrations per second. The note of a piano produced by a string which vibrates 256 times in a second, is also produced by a flute in which a column of air vibrates the same number of times in a second.

To ascertain the particular pitch of any sound, we must have some means of measuring the particular lengths of the different waves by which the sound is made sensible to the ear. These are furnished by an instrument called—

The Syren.—This instrument, as lately improved by Mr. Ladd, consists of a cardboard disc, of about $\frac{3}{8}$ of an inch in thickness and 24 inches in diameter, containing 1,682 perforations. This disc is made to revolve rapidly by means of a multiplying wheel. A jet of air, either from a pair of bellows or through a short tube from the mouth, held nearly close to it, is thrown on the disc when in motion. By this instrument 15 notes and 7 chords are produced. The pitch increases with the velocity of the disc. Connected with the axis of rotation of the disc is a stop register, to indicate the number of revolutions, and a stop watch is sometimes attached, to indicate the time. Suppose the disc to contain n number of holes, and the number of revolutions to be r, and the number of seconds S; the number of impulses, and therefore the number of waves, will be $n.r$, and the number of waves produced in one second will be $\frac{n.r}{S}$. But the waves generated in one second occupy the entire distance denoted by V, the velocity of sound. Let L be the wave length; then, according to M. Biot,—

$$\frac{n.r}{S}.L = V = 1089{\cdot}42 . \sqrt{1 + (t - 32^\circ)\, 0{\cdot}00208}\,;$$

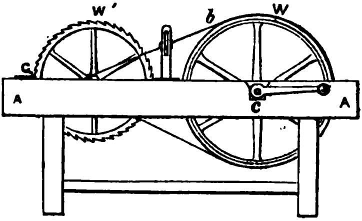
and $$L = \frac{1089{\cdot}42 . S . \sqrt{1 + (t - 32^\circ) . 0{\cdot}00208}}{n.r};$$

—whose experimental researches on this subject are given in the following table :—

	Number of Vibrations in one Second.	Length of Resulting Wave in Feet.
	1	1,091·34
	2	545·67
	4	272·83
Probable utmost range audible to the human ear.	32	32·10
	64	17·05
	128	8·52
	256	4·26
	512	2·13
	1,024	1·06
	2,048	0·53
	4,096	0·26
	8,192	0·13

Another instrument, *Fig.* 2, is sometimes employed to determine the number of vibrations. A A is a solid

FIG. 2



framework of wood, which supports a large wheel, W; from this wheel motion is communicated to a cog-wheel, W′, by means of a band, *b*; the teeth of this cog-wheel strike against a piece of card, C; the successive shocks given to the card are imparted to the atmosphere. When the velocity of the cog-wheel is small, a succession of gentle taps are heard, but as the velocity increases these taps appear to unite to produce a con-

tinuous note, the pitch of which is determined by the rapidity with which the card is struck. If we know the number of revolutions made by the wheel in a second, and also the number of teeth in the wheel, we can easily determine the number of strokes given to the card in a second of time. By this instrument a note of the same pitch can be produced as that of a gnat, a bee, or a beetle, when it flaps its wings, and the number of these per second can be inferred with the greatest accuracy.

If we know the number of vibrations which occur in one second, we can easily calculate the length of the corresponding waves of air. If sound passes over 1,120 feet in a second of time, and the string vibrates 440 times, when the string makes its last vibration the first wave is 1,120 feet distant. In the space between the point from which the vibrations originate, and a distance of 1,120 feet, there must be 440 waves; and to find the length of one wave, we must divide the space 1,120 by the number of vibrations 440, which gives $2\frac{6}{11}$. From experiments by M. Savart, it appears that a gnat flaps its wings 13,000 times in a second. Here, then, we have, in the space of 1,120 feet, 13,000 waves. Reducing the feet to inches, and dividing the number of waves, we obtain the length of these aërial undulations.

From these experiments it has been inferred that the lowest pitch audible is that produced by a wave whose length is 32·10 feet, of which there are generated, in one second of time, 32 in number; and that the highest audible pitch is given by a wave whose length is 0·13 foot, of which 8,192 are generated in a second. Some have contended for a higher number. M. Savart, by means of an instrument similar to the one just described, found that 12,000

strokes on the card in one second produced a musical tone of high pitch.

Although authorities differ with regard to the power of hearing, they all agree in ascribing to it a limit. In some animals the power may commence where it ceases with us, and they may have the faculty of hearing sounds of a much higher pitch than we actually know, from experience, to exist.

RÉSUMÉ.

Sound is caused by the vibration of sonorous bodies.

Sound is transmitted by means of bodies interposed between our ear and the sounding body.

Sound is not produced in a vacuum.

The vibrations of a sonorous body impart to the air an undulatory motion, which falls on the membrane of the tympanum, and causes it to vibrate and produce the sensation of sound.

The intensity of sound depends on the force with which the vibrating particles of air strike the membrane of the ear.

The intensity of sound decreases from the point where it originates inversely as the square of the distance.

The velocity of sound is usually estimated at 1,120 feet per second. For every variation of a degree above or below 62° F., the velocity either increases or diminishes at the rate of about 13 inches.

Musical sounds are produced by the uniform vibrations of a sonorous body, which impart to the air undulations exactly alike in duration and intensity, and recur after exactly equal intervals of time.

Rapid vibrations produce *acute sounds.*

Slow vibrations produce *grave sounds.*

When one note is caused by twice the number of vibrations in a given time which another makes, it is said to be *an octave.*

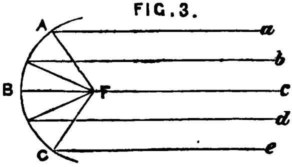
To obtain the length of sonorous waves, we divide the space per second, 1,120 feet, by the number of vibrations in the same time.

Reflection of Sound.—If the sound waves strike against any smooth, fixed surface, they rebound from that surface, and the angle of reflection is equal to the angle of incidence. This law is, in fact, the same as that which governs the reflection of all elastic bodies, and also heat and light.

An Echo is produced when the ear is able to distinguish the direct sound produced by the reflection of the sound waves. A delicate ear will perceive about nine successive sounds in one second of time,—that is to say, the sounds must not succeed each other more frequently than at intervals of one-ninth of a second of time to be heard singly. The interval of time between the sound and its echo depends on the difference of direction travelled by the direct and reflected sound. In order to produce an echo, the reflecting surface must be situated at such a distance from the source of sound, that the interval between the hearing of the original and reflected sound must be sufficient to prevent them being blended together, which gives rise to what is called RESONANCE. It is this resonance from the walls of a room that makes it easier to speak than in the open air. In rooms where there are curtains, stuffed furniture, and carpets, the sound waves are broken, and the resonance diminished. In deserted and unfurnished rooms the sound is more distinct.

When sound is reflected from several surfaces, situated in different directions and at different distances, multiplied echoes are heard. A river with perpendicular walls of rock on each side reflects the sound backward and forward over the smooth surface of the water. At Lurley-Fels, on the Rhine, a sound is repeated by echo seventeen times; and at the Villa Simonetta, near Milan, the sound is repeated thirty times. If the surface upon which sound waves strike be concave, the sound may be concentrated and reflected to a point at some distance from the surface, called the focus (*Fig.* 3). If the sound waves, proceeding in straight lines from the points *a b c d e*, strike upon the concave surface A B C, they will be reflected to the focus F, and produce a powerful effect. It is on this principle that WHISPERING GALLERIES are constructed, where the faintest whisper uttered at one point is distinctly heard at another distant point, without its being audible at intermediate positions. The proper form of these galleries is that of the ellipsoid of revolution. In such a chamber, two persons—one in either focus—can keep up a conversation with each other which is quite inaudible at other points.

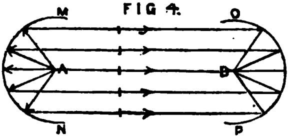
FIG. 3.



Halls for speaking and churches should be constructed so as to diffuse the sounds throughout the whole space, unimpaired by any echo or resound; and if the speakers always occupied the same position, the parabolic form is no doubt the best. Everything should be avoided that interferes with the uniform diffusion of sounds; all need-

less hollows and projections should be avoided. The following simple experiment (*Fig.* 4) will illustrate the consequences arising from the reflection of the rays of sound from the interior of a parabola. Place a watch in the focus A of a parabolic mirror, and all the sound rays that fall on the concave surface will be reflected in the direction indicated by the arrows. The ticking of the watch will be distinctly heard within the space M N O P, in which the rays fall; but it will not be perceptible at a small distance on either side. Now place the reflector O P opposite to M N, and at some distance from it; the sound rays will be received by it, and thrown into the focus B. If the ear, or the mouth of a hearing trumpet, be applied to this part, the ticking of the watch will be heard almost as plainly at B as at A.

FIG 4.



The Speaking Trumpet is a hollow tube, so constructed that the sound rays, instead of diverging and being scattered in the surrounding atmosphere, are reflected from the sides and conducted forward in straight lines.

In the Hearing Trumpet, which is intended to assist persons hard of hearing, the principle is reversed. The sound rays enter at the larger end, and are so reflected as to become united at the smaller end, which is placed in the ear.

From the known velocity of sound it is not difficult to calculate the distance between two places. Let a pistol be fired, and the time carefully noted between seeing the flash and hearing the report. Let this interval of time be expressed in seconds, and multiplied

by $1089{\cdot}42 \sqrt{1 + (t - 32^\circ) . 0{\cdot}00208}$ will give the distance in feet, and the value t will be given by the Fahrenheit thermometer. In this calculation the direction and velocity of the wind are neglected.

RÉSUMÉ.

When the undulations of the air strike any smooth, fixed surface, they rebound or are reflected.

An echo is produced when the ear is able to distinguish the direct sound produced by the reflection of the sound waves.

If the surface on which the sound waves strike be concave, these may be all concentrated to a point called the focus.

In speaking trumpets the undulations, instead of diverging and being scattered in the surrounding atmosphere, are reflected from the sides, and carried forward in straight lines. The same principle is employed in SPEAKING TUBES used for communicating between different apartments in the same building.

In hearing trumpets the undulations enter the larger end, and are reflected so as to become united at the smaller end.

LIGHT.

Optics is that branch of physics which treats of the phenomena of light. The sensations of external objects are derived through our sense of sight. The nature of light is, in some degree, still doubtful.

Two theories have been advanced to explain the phenomena of light,—the corpuscular or emission theory, and the undulatory or wave theory.

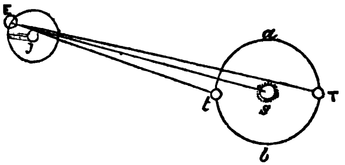
The advocates of the corpuscular theory maintain that light is a peculiar matter projected in every direction from luminous bodies in a succession of material particles, which move with immense velocity through space, and falling on the retina of the eye produce the sensation of light. This theory has been sustained by Newton and Laplace; but certain difficulties in some recently discovered properties of light, especially with regard to its polarization, have tended to revive the undulatory theory, viz., that all the phenomena of light depend on the undulations of an extremely attenuated and highly elastic medium called ether. This ether permeates all bodies and pervades all space, and when acted on by luminous bodies is thrown into a succession of pulsations or waves, which are propagated in every direction, and constitute the phenomena of light. These ethereal waves are admitted into the eye, and the sensation of sight arises from the motions which these waves communicate to nerves which are spread over the internal surface of that organ. We therefore see by a principle in every respect analogous to that by which we hear; the only difference being in the nature of the medium

proper to excite these different sensations. In the one case the ether agitates the nerves of the eye; in the other the air communicates its vibrations to the ear. This theory has been ably maintained by Euler and Descartes. Almost all the leading principles regarding light may, however, be explained by either theory. Both assume the existence of a subtle fluid or ether, and the influence of luminous bodies. In both theories light must be considered as a material body possessed of certain well-defined properties.

The velocity of light was first determined by Von Roemer, a Swedish astronomer, in 1678, by observations on the satellites of Jupiter. This planet is surrounded by several satellites, or moons, which revolve about it in certain definite times. As they pass behind the planet they disappear to an observer on the earth, or, in other words, they undergo an eclipse. The earth revolves in an orbit about the sun, and in its revolution is at one point 192 millions of miles nearer to Jupiter than when it is in the most distant part of its orbit. Suppose a table, calculated by an astronomer at the time when the earth is nearest to Jupiter, showing for twelve months the exact time when a particular satellite would be eclipsed at that point. In the space of six months from that time the earth, in its revolution, has arrived at a point in its orbit 192 millions of miles more remote from Jupiter than when the table was calculated; and it would be found that the eclipse of the satellite would occur 960 seconds later than the calculated time. This is explained by the fact that the light has to pass over a greater space than when the earth was in that part of its orbit nearest to the planet; and if it requires 960 seconds, or 16 minutes, to move over 192 millions of miles, it will require one second to pass over 200,000

miles. When the earth in six months arrives at its former position, or 192 millions of miles nearer to Jupiter, the eclipse will occur 16 minutes earlier, or at the exact time calculated. The velocity of light may, therefore, be assumed as 200,000 miles per second; but more exact calculations give 192,500 miles per second. A reference to the following diagram (*Fig.* 5) will make the illustration much clearer:—

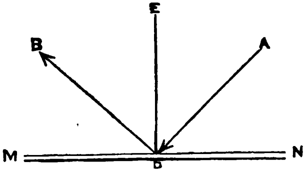
FIG. 5.



Let S represent the sun, and a b the earth's orbit; T and t the position of the earth at the opposite points of its orbit. J represents Jupiter, and E its moon or satellite, about to be eclipsed by passing within the shadow of the planet. Now the commencement or termination of an eclipse is the instant of time when the satellite enters or emerges from the shadow of the plane. If the transmission of light were instantaneous, it is evident that an observer at T, the most remote part of the earth's orbit, would see the eclipse begin and end at the same time as an observer at t, the part of the earth's orbit nearest to Jupiter. This, however, is not the case. The observer at T sees the eclipse 960 seconds later than the observer at t; and as the distance between these two points is 198 millions of miles, we have the velocity of light in one second $\frac{192,000,000}{960} = 200,000$.

Reflection of Light.—When the rays of light fall on any surface they may be reflected, absorbed, or transmitted. A portion only of the light which falls on any surface is reflected; the remainder is absorbed or transmitted. When the light reflected from any surface or point of a surface to the eye is considerable, such surface or point appears white; when partly reflected and partly absorbed it appears dark-coloured; but when all the rays are absorbed and none reflected the surface is black. Charcoal is black because all the rays of light which fall on it are absorbed, and such a body is not seen unless surrounded by other bodies from which the light is reflected. Let A D (*Fig.* 6) be a ray of light which falls on a

FIG. 6.

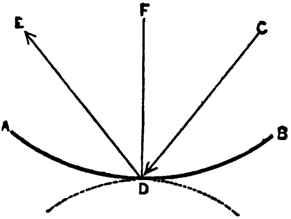


plane speculum, and strikes it at the point D. This ray will be thrown back in the direction D B, so inclined to ray A D, that if we raise from the point D a line perpendicular to M N, the angle B D E will be equal to the angle A D E. The ray A D is the incident ray, and the ray D B the reflected ray. The angle of incidence, A D E, is equal to the angle of reflection, B D E. The same law holds good with regard to curved surfaces.

If the reflecting surface is concave, or part of a sphere (*Fig.* 7), as A B, a ray of light, C D, falling on the point D, will be reflected in the direction D E, forming the same angle with a line, F D, drawn from

the centre of the sphere to the point where the incident ray falls. If the surface of the speculum be

FIG. 7.



convex, the same law holds, viz., that the angle of incidence is equal to the angle of reflection.

Definitions.—Parallel rays are those which are parallel or equidistant. Divergent rays are those which issue from a point and separate from each other, forming an angle. Convergent rays are those which approach each other, or converge to a point.

A Plane Mirror is one in which the reflecting surface is plane. Ordinary plane mirrors, or looking-glasses, are plates of smooth glass with the back covered with a thin layer of mercury and tinfoil. The images formed by a looking-glass are produced by the reflection of the rays of light from the metallic covering, and not from the glass. If the surface of a plane mirror could be so highly polished as to reflect all the rays incident upon it, the mirror itself would be invisible, and an observer would see nothing but the images of the objects before it. Such a mirror placed vertically against the walls of a room appears like an opening leading to another apartment, and a person is only prevented from walking through it by meeting his own image. We always seem to see an object in the direction in which the rays of light enter the eye.

A mirror which changes the direction of the rays proceeding from an object will change the apparent place of that object. Let a looking-glass be placed horizontally on a table, and let the rays of a candle fall obliquely on the mirror and be reflected to the eye, we shall seem to see the candle inverted, and as much below the surface of the glass as the candle is above it.

When a person stands before a looking-glass, the rays of light which proceed from each point of our body will, after reflection, proceed as if they came from a point occupying a corresponding position behind the glass, and will produce an effect upon the eye as if they had actually proceeded from that point. The image, therefore, appears as much behind the glass as the person is before it. Let (*Fig.* 8) A B be a

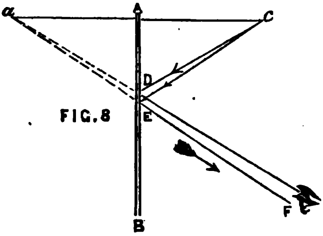
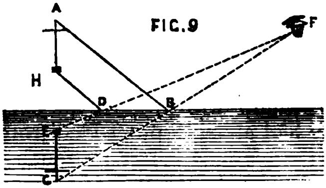


FIG. 8

plane mirror or looking-glass, and *c* an object placed before it. Let *c* D and *c* E be two rays diverging from the object, and reflected from D and E to the eye at F. After reflection they will proceed as if they had come from a point *a*, as far behind the surface of the glass as *c* is before it; that is, the distance *a* A is equal to the distance *c* A. For this reason our reflection in a mirror appears to approach when we move towards it, and retire when we walk away. (*Euclid*, Book i.)

When trees or houses are reflected from the smooth horizontal surface of a sheet of water, they all appear bottom upwards, because the light of the object reflected to our eyes from the surface of the water comes to us in the same direction as it would have done had it proceeded directly from an inverted object in the water. In *Fig.* 9 the ray of light proceeds from a

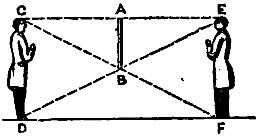
FIG. 9



cross A, strikes the water at B, and is reflected to C, and that from the base H strikes the water at D, and is reflected to E. A spectator at F will see the reflected rays B C and D E, as if they had proceeded directly from E and C, and the image of the cross will appear to be at E C from the surface.

On a comparatively small plane mirror, the size of which could be easily determined, a person may see the whole of his figure by standing at a distance from the surface. Let A B (*Fig.* 10) be a plane

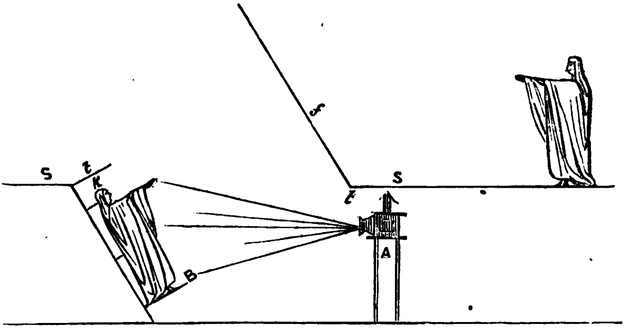
FIG. 10



mirror. The rays of light C A, which proceed from the head of the person, fall perpendicularly on the mirror, and are reflected back in the same line. The rays D B, proceeding from the feet, fall at an angle on

the surface of the mirror, and are therefore reflected at an angle, and reach the eye in the same direction they would have taken had they come from a point F behind the mirror.

Pepper's Ghost.—This optical illusion is entirely due to the reflected image of a living person. To produce this effect, the platform, or ordinary stage, must have another stage or platform below it. This lower stage is strongly illuminated by an artificial light from a lime ball or electric light, A. The visible

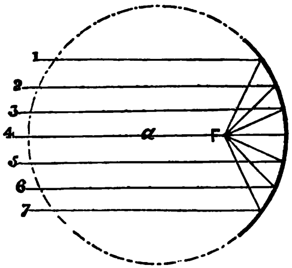


stage, S S, has two trap-doors, *t t*, and is lit in the ordinary way. A large glass screen, *f*, is placed in front, and at such an inclination as persons can see the reflected image. The actor or actors corresponding to the images are hidden from the audience by being on the lower stage, B. The person or persons acting are strongly illuminated, and the light is so managed that it may be instantly masked or extinguished, so as to make the image appear and reappear at pleasure. The raised part of the trap-door in front of the ordinary stage helps to screen the light from

the audience. The actor, while on the stage B, leans against a screen, *k*, covered with black cloth, and parallel to the glass screen *f*. The scenery is so arranged as to hide the frame of the glass *f*, and under a subdued light the glass and frame may be either raised or lowered out of sight, so as to allow a person to pass across the space which the glass occupied, and thus make the illusion more perfect. In order that the image should appear upright on the visible stage, the person on the lower stage should be so inclined as to be parallel to the glass screen; and as the person acting cannot see his own image, marks are made on the lower stage, so that he may know the position of his image with reference to the audience.

A Concave Mirror may be regarded as the interior surface of a portion of a hollow sphere. When parallel rays of light fall on the surface of a concave mirror, they are reflected and converge to a point in front of the mirror, and this point is called the focus. Let (*Fig.* 11) 1 2 3 4 5 6 7 be parallel rays of light

FIG. 11.



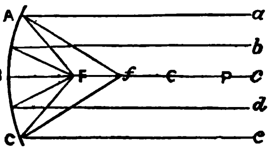
falling upon a concave mirror. After reflection they will converge to a point F, the principal focus, which is situated halfway between the centre of the surface of

the mirror and the geometrical centre, *a*, of the curve of the mirror. These mirrors are sometimes called burning mirrors, since the rays of the sun are converged to a focus or fire-place, where the light and heat are concentrated.

The rays of a luminous body placed at the centre of the curve of a concave spherical mirror will be reflected back to the point from which they diverged, and the rays would meet again at the centre, in obedience to the law just described.

If diverging rays, issuing from the principal focus, fall on a concave spherical mirror, they will be reflected in parallel lines. Let F (*Fig.* 12) be a candle placed in the principal focus of the concave mirror; A B C, the rays falling on the mirror, will be reflected in straight lines. This form and arrangement of mirrors is taken advantage of in illuminating lighthouses.

FIG. 12



When the rays issue from a point, P, beyond the centre of the curve of the mirror, they will, after reflection, converge to a focus *f*, between the principal focus F and the centre of the circle *c* formed by continuing the curved line. And if the rays issue from a point between the principal focus and the surface of the mirror, they will diverge after reflection.

When the object is placed between the principal focus of a concave mirror the image is vertical and erect. It is also larger than the object, or magnified.

Let *a* be an object (*Fig.* 13) within the principal focus of the mirror. The rays from the extremities, as we have just seen, will fall divergent on the mirror, and be reflected less divergent to the eye at *b*, as though they

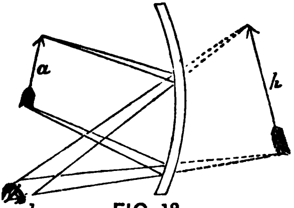


FIG. 13.

proceeded from an object behind the mirror, as at *h*. To the eye at *b*, the object will also appear larger than the object *a*, since the angle of vision is larger.

When any object is at a greater distance from the surface of a concave mirror than its principal focus the object will appear inverted, but when the object is placed between the mirror and its principal focus the image will be upright, and increase in size in proportion as the object is nearer the focus.

A Convex Mirror may be considered as the exterior surface of any portion of a sphere. The principal focus of a convex mirror lies as far behind the reflecting surface as in concave mirrors it is before it. As this focus is only an imaginary point, towards which the rays of reflection appear to be directed, it is called the virtual focus. The general effect of convex mirrors is to produce an image smaller than the object. The globular bottles filled with coloured water in a chemist's window exhibit all the variety of moving scenery in the street. In the upper half of the bottle all the images are inverted, and in the lower half they are in an erect position. These mirrors are sometimes called dispersing mirrors, because all the rays of light which fall on them are reflected in a diverging direction.

Refraction.—The bending or deviation which the rays of light undergo in passing from one medium to

another is called refraction. A medium, in optics, is any substance through which light can pass. A medium is either dense or rare according to its power of refracting light, and not according to its specific gravity. For instance, alcohol, olive oil, and turpentine have a less specific gravity than water, but have a greater refractive power. The laws which govern the refraction of light are as follows :—

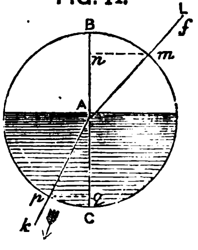
1. The planes of incidence and refraction coincide, both being normal to the surface separating the media at the point of incidence.

2. The sine of the angle of incidence is equal to the line of the angle of refraction multiplied by a constant quantity.

The constant quantity referred to varies with the media, but is the same for any given medium. It is called the *index of refraction.*

Let A (*Fig.* 14) be the point of incidence separating air from water. With A as a centre describe the circle B *m* C *p*. Let L A be an incident ray, and A *k* the refracted ray. Draw *m n* and *p q* perpendicular to the normal B C. Then will these lines be the sines of the angles of incidence and refraction, and we shall have, in the particular case of air and water, *m n* equal *p q* multiplied by $1\frac{1}{3}$, whatever may be the inclination of L *k*. Here $1\frac{1}{3}$ is the index of refraction. For air and glass the index of refraction is $1\frac{1}{2}$.

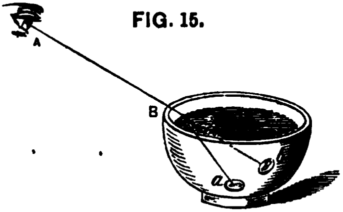
FIG. 14.



A straight stick partly immersed in water appears broken or bent at the point of immersion. This is owing to the fact that the rays of light proceeding from that part of the stick under water are

refracted, or deviate from a straight line, as they pass from the water into the air. That part of the stick in the water will appear lifted up or bent in such a way as to form an angle with the part out of the water. A spoon in a glass of water, or an oar partially immersed in water, always appears bent. A person endeavouring to strike a fish under water must, unless he be immediately above it, aim at a point apparently below it. Let a shilling be placed at the bottom of a basin, as at *a* (*Fig.* 15), in such a manner

FIG. 15.



that the eye at A cannot perceive it. Then let some one fill the basin gently with water, so as not to disturb the shilling. The coin now rises into view just as if the bottom of the basin had been elevated. It will, by the refraction, be seen not in its true place, *a*, but in the direction A B. The rays from the shilling, on entering the air, which has a much less refractive power than the water, are turned towards the surface of the water; and the rays so emerging, some will proceed to the eye, and the image of the shilling will appear in the direction of the ray entering the eye. A clear stream, viewed obliquely from the bank, appears more shallow than it really is, since the light, appearing from the objects at the bottom, is refracted as it emerges from the water. The depth of water, under such circumstances, is about a third more

than it appears—a useful fact for boys to bear in mind when bathing.

The light, on entering the atmosphere, is refracted according to its density; and as that portion of the atmosphere nearest the surface possesses the greatest density, it must also possess the greatest refractive power. From this cause the sun and other celestial bodies are never seen in their true position unless they happen to be vertical, and the nearer they are to the horizon the greater will be the influence of refraction in altering their apparent places. Morning does not occur at the instant of the sun's appearance above the horizon, nor does night commence the instant the sun disappears below it. Both at morning and evening the rays proceeding from the sun below the horizon are refracted by passing through the atmosphere, or bent down towards the surface of the earth. As the density of the air diminishes from the surface of the earth, there is not that sudden change of direction we observe in a stick partly immersed in water; but a ray of light proceeding from any celestial body describes a curve, being more and more refracted at each step of its progress through the atmosphere. This also applies to light received from distant objects on the surface of the earth which are higher or lower than the eye.

Total Reflection.—When light passes from a medium to one more refractive it will always be refracted; but not so when it passes into a less refractive medium, as when it passes from water or glass into air. In this case the angle of incidence is limited, beyond which refraction cannot take place. Let B M C (*Fig.* 16) represent a hollow globe half full with water. A ray of light coming from L to A, being normal to the surface of the globe, experiences no refraction

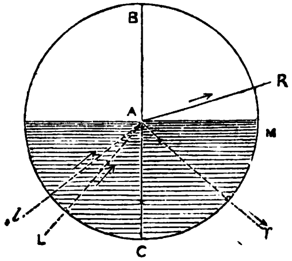


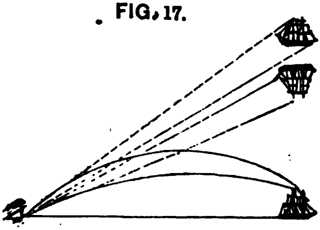
FIG. 16.

there; but on reaching A, if the angle of incidence L A C is small enough, it will be refracted from the normal B A, and pass out into the air in some direction such as A R. If now the angle of incidence exceeds 41°, as is the case with the ray *l* A, it can no longer pass the surface A M, but is reflected in the direction A *r*, making the angle *l* A C equal to the angle C A *r*. This kind of reflection at the surface which separates two media is called internal or total reflection. It is called total reflection because all the light is reflected, which is not the case under any other circumstances of reflection, no matter how carefully the reflecting surfaces may be polished.

Mirage.—The term "looming" is given by sailors to express a curious optical deception by which objects come into view, though materially altered as to their shape and position. The French call it "*mirage;*" the Italians, "*Fata Morgana.*" It often happens that ships appear as if painted in the sky, and not resting upon the water. Rocks and sands appear raised above the surface. The Swedes long searched for an illusory island of this sort, which they saw from a distance placed between the isles of Aland and the coast of

Upland. These phenomena are due to a change in the density of the air which lies immediately on the surface of the earth. When the surface of the earth is greatly heated, the strata of air in contact with it become more rarefied than other strata resting on the surface of the water, or occupying more elevated regions. Rays, therefore, proceeding from distant objects, and passing through these strata of different density, will be unequally reflected, and proceed in a curvilinear direction; and in this way an object behind a hill or below the horizon may become visible and appear suspended in the air. Suppose the rays of light from a ship (*Fig.* 17) below the horizon

FIG. 17.



to reach the eye after passing in a curvilinear direction through air of different density. Then, as an object always seems to be in the direction in which the last rays proceeding from it enter the eye, two images will be seen in the direction of the dotted line, and one of these images will be inverted. These effects may be illustrated by heating an iron rod and then placing it in a horizontal position. The air in contact with the upper surface of the iron will be more rarefied than that at some distance above it, and thus the order of density will be to a small height inverted; consequently, in looking horizontally along the bar to any

object a little height above it, its direct image will be seen by means of horizontal rays, and an inverted image will be seen below it by reflected rays.

A medium whose two sides are parallel will suffer no permanent change by refraction, since the second face or surface exactly compensates for the refractive effect of the first. Let A B (*Fig.* 18) be a plate

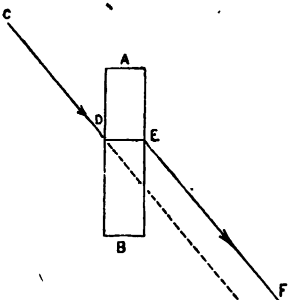


FIG. 18.

of glass, and C D a ray of light incident upon it. It will be refracted in passing through the glass, and again on emerging in the direction of the line E F, parallel to C D. Hence, in looking through a window, if it has good glass we do not see the direction of objects changed.

If the surfaces of the medium through which light passes be not parallel, the direction of every ray passing through it is permanently altered, and the greater the inclination of the two surfaces the greater the alteration.

A Prism.—On looking through a prism all objects appear removed from their true position. Let C A B (*Fig.* 19) be a prism, and *a e* a ray of light incident on it. In passing through the prism it will be refracted in the line *e g*, and on emerging it will be again

refracted in the direction $g\ h$; and as objects always appear in the direction in which the last ray enters the eye, the object a will appear at f.

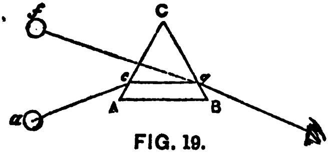


FIG. 19.

Lenses.—A lens is a refracting medium bounded by curved surfaces or by one curved and one plane surface. Lenses are usually made of glass. There are six kinds of lenses, according to the nature of the bounding surfaces.

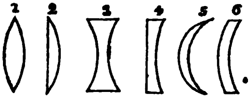


FIG. 20.

1 is a double convex lens, bounded by two convex surfaces. When the curvature of the two surfaces is the same the lens is said to be equally convex.
2 is a plano-convex lens.
3 is a double concave lens.
4 is a plano-concave lens.
5 is a lens called a *meniscus*.
6 is a concavo-convex lens.

Nos. 1, 2, and 5 are thicker in the centre than at the edges. These collect the rays of light, and are convergent lenses. Nos. 3, 4, and 6 are divergent lenses. The centres of the bounding surfaces of a lens are the centres of curvature, and a straight line through the centres of curvature is called the axis of the lens.

In all lenses, no matter what the form of their surfaces may be, there must be a point through which the rays of light passing experience no deviation, or, in plain words, the incident rays and the emergent rays are parallel. Such a point is called the optical centre of a lens. In practice it is usual to make the surfaces which bound double concave lenses equally curved. When this is the case, the optical centre is on the axis and midway between the two surfaces of the lens, and a ray passing through this centre is not deviated by the lens.

Parallel rays of light falling on a double convex lens are converged to a focus at a distance varying with the curvature of its surface. A double convex lens may be regarded as made up of two prisms, with curved surfaces, united at their bases; and as in a prism a ray of light is refracted towards the thickest part, no matter in what position it may be placed, it follows that when parallel rays fall on a double convex lens, or two prisms, they will converge to a point. The point where these parallel rays unite, after refraction, on the opposite side of the lens, is called the principal focus of the lens; and the distance from the centre of the lens to the principal focus is called the focal distance. This, in a single convex lens, is equal to the diameter of the sphere of which the surface of the lens forms part; in a double convex lens it is equal to the radius of the sphere of which the lens is a portion. The focus of a convex lens is easily found experimentally by allowing the rays of the sun to fall perpendicularly upon one side of it, while a sheet of white writing paper is held on the other. A bright ring of light will be observed on the paper, which will increase or diminish in size according as the paper is brought nearer or removed

from the glass. From this property of converging the rays of light, convex glasses, like concave mirrors, may be used for the production of a high temperature, by concentrating the sun's rays.

Rays of light falling on a concave lens are so refracted that they diverge on emerging from the lens as though they issued from a focus behind it. The focus, therefore, of a concave lens is not real but virtual, as in the case of a convex mirror.

When parallel rays fall on a double concave lens, they are so refracted, in passing through it, that they are made to diverge as though proceeding from a point behind the lens.

Images are formed in the foci of convex lenses in the same way as in the foci of concave mirrors.

If we take a convex lens and place behind it, at a proper distance, a sheet of white paper, there will be thrown clear and distinct images of all the objects in front of it in an inverted position. The manner in which they are formed is represented in *Fig.* 21.

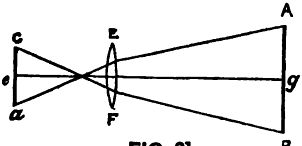


FIG. 21.

Let A B be an object placed before a double convex lens. The rays proceeding from A, the top of the object, will be converged by the lens and brought to a focus at *a*, where they will form an image. The rays proceeding from the base, B, will be converged and brought to a focus at *c*, and so with each point of the object A B, which will have its corresponding image

between *c a*; and in this way a complete image will be formed, in an inverted position. The centre ray, *e g*, undergoes no refraction.

Convex lenses, as ordinarily used, are called magnifying glasses, because they increase the apparent size of the objects: and the reason is obvious. The lens so alters by refraction the rays of light proceeding from an object, that they enter the eye as if they came from points more distant from each other than is actually the case, and the object appears magnified. Concave lenses produce exactly the opposite effect, and cause the image of an object to appear smaller. It is on the same principle that concave mirrors magnify the images of objects and convex mirrors diminish them. The magnifying and diminishing power of lenses is due to the figure of their surfaces, and not to the material of which they are made.

Spherical Aberration.—Lenses are also subject to an imperfection called spherical aberration. This arises from the fact that the curved surface of a lens is at unequal distances from the object, and from the screen which receives the image formed at its focus; and hence, if one point of the image is perfect, another point is less so, owing to the difference in the convergence of the rays coming from the centre and edges of the lens.

If the image of an object be received on a ground glass screen placed exactly in the focus of the lens, the image will be well defined in the centre but indistinct at the edges; and if the image be sharp at the edges it will be indistinct at the centre. This defect is very objectionable, especially in lenses used for photography. To make the image perfect the marginal portions of the lens should be covered with a circle of paper, so as only to permit those rays to pass

through which lie near the axis of the lens. This arrangement cuts off those rays which pass near the edges. When the image formed is small, the spherical aberration is scarcely noticed, and by a combination of lenses of different refractive power it may be entirely overcome.

An achromatic lens consists of two or more lenses, made of different kinds of glass, so constructed as to neutralize the effects of dispersion. The combination usually consists of two lenses—a convex, made of crown glass, and a concave, made of flint glass. Flint glass disperses the light more than crown glass. The dispersion of the rays by one of the lenses is exactly neutralized by the dispersion in an opposite direction of the other, so that the image is nearly colourless. Such combinations are called achromatic, and are used in the construction of telescopes.

RÉSUMÉ.

Light, according to recent experiments, moves with a velocity of 192,500 miles per second.

The rays of light move in straight lines from the luminous body.

The point of intersection of the rays of light is called *the focus.*

Rays of light may either be parallel, divergent, or convergent, and bodies on which the rays fall may be transparent, semi-transparent, or opaque.

The intensity of light is inversely as the square of the distance—that is, in the ratio of 1, 4, 9, 16, &c.

Rays of light falling on a reflecting surface are called the incident rays, and the rays reflected are called the reflected rays.

A perpendicular line drawn to the reflecting surface

is called a normal, and the angle contained by the incident ray and the normal is the angle of incidence.

The angle of incidence is always equal to the angle of reflection.

A mirror may be plane, as an ordinary looking-glass, or the surface may be concave or convex.

If parallel rays of light fall on a *double convex lens*, the rays, in passing through, will be refracted towards the axis of the lens, and meet at a point beyond it called the focus. The distance of the focus from the surface of a lens will vary with the refractive power of the substance of which it is made.

In a lens made of glass, and both sides equally convex, the focus is nearly at the centre of the sphere of which the surface of the lens forms a portion.

Lenses with a *convex surface* collect the rays of light to a focus.

Lenses with a *concave surface* disperse them.

Lenses with one side flat and the other convex are called plano-convex.

The focus of a plano-convex lens is at the distance of the diameter of a sphere of which the convex surface of the lens forms a portion.

Lenses with one side flat and the other concave are called plano-concave.

An achromatic lens is one made of crown and flint glass, so as to neutralize the dispersion of the rays, and produce perfectly distinct images, free from colour about their edges. A convex lens is usually made of crown glass united to a concave lens made of flint glass.

Reflection of Plane Mirrors.—All the rays from any radiating point which fall on a plane mirror are reflected from the surface in such a manner that they seem to proceed from a point behind the mirror. Now

this point is situated exactly where the reflected rays, if produced, would intersect each other, and this point will be as far beyond the mirror as the point from which the rays proceed is before it. This point is called the virtual focus.

Spherical Mirrors.—The centre of the spherical surface of which the mirror is a portion is the geometrical centre, or centre of curvature. A point in the surface of a mirror equidistant from all parts of the circumference of a sphere of which the mirror is a portion, is the optical centre or vertex of the mirror. A line passing through these two points is the axis of the mirror. The reflection of light from a spherical mirror obeys the same law as in plane mirrors.

All the rays which fall on a concave mirror parallel to its axis will be so reflected that each of them will intersect the axis after reflection. If these rays be very near the axis they will cut it, after reflection, at a point midway between the optical and geometrical centres, and this point is called the focus, and its distance from the optical centre, or vertex, of the mirror is the focal distance, and it is always equal to half the radius of that sphere of which the mirror forms a segment. The other points of the axis through which the rays of light cut are called foci, and their respective distances from the optical centre, or vertex, are called their focal distances. The focus of parallel rays is called the principal focus, and its distance from the optical centre the principal focal distance of the mirror. The parallel rays near the axis of a concave mirror will be reflected so as to cut each other at the principal focus. The limit within which this is true is, however, rather narrow, for the parallel rays must not exceed 15° from the geometrical centre: if they do, they will not be reflected so as to meet at the principal focus.

All divergent rays from a radiant point placed in the focus of a concave mirror will be reflected from its surface in lines parallel to the axis, if their distance does not exceed 15° from the vertex or optical centre of the mirror. Such rays will not intersect each other.

Rays proceeding from any radiant point beyond the geometrical centre of a concave mirror, or which cross the axis at a point beyond such centre, will be reflected so as to cut the axis between the focus and centre of curvature; and if the rays intersect the axis between the focus and geometrical centre of a concave mirror, they will be reflected so as to cut the axis again in another point beyond the focus. All rays coming from a point between the mirror and the focus will be reflected from the surface so as to diverge from the axis.

If there be any radiant point before a mirror, the virtual focus of that point may be determined mathematically by producing the reflected rays till they meet, and this point will be the virtual focus.

In concave mirrors the image of remote objects will appear in the focus of the mirror, and extremely small; and every object which is a greater distance from the mirror than its centre produces an image between this point and the focus smaller than the object itself, and inverted. If the object be at a distance from the mirror equal to the length of its radius, then the image will be an equal distance from the mirror. Its size will be the same as the object, but its position will be inverted. If an object be between the focus and the geometrical centre, then the image will be inverted, and its size will exceed that of the object. If a luminous body be placed in the focus of a concave mirror, no image will be produced, but the whole surface will be illuminated, because all the rays are reflected in parallel straight lines. If an object be

placed between the mirror and the focus, its image will be behind the mirror: it will not be inverted, but its size will be increased according to the nearness of the object to the focus. In this case the reflected rays diverge and intersect at points behind the mirror, so that they appear as if they really proceeded from these points of intersection.

In convex mirrors the focus is as far behind the surface as in concave mirrors it is before it. It is generally called the virtual focus, because it is only an imaginary point, and not formed by the actual union of rays in a focus. All parallel rays which fall on a convex mirror will diverge as if they proceeded from a focus behind the mirror.

The images of objects formed by spherical convex mirrors invariably appear beyond the mirror. They are virtual images. They are also seen in their natural positions. They are smaller than the objects themselves. The farther the object is from the mirror the smaller the image. If the object is very distant its image will be in the virtual focus of the mirror.

The Eye is a collection of refractive media which concentrate the waves of light proceeding from every point of an external object on a tissue of delicate nerves called the retina, there forming an image from which our perception of the object arises. These media are contained in a globular envelope of four coverings; two of which make up the external enclosure of the eye; the others serving as a covering to the larger of these two.

The shape of the eye is spherical, except just in front, where it projects beyond the spherical form, as at *d e d*. The figure represents a section of the human

eye through the axis by a horizontal plane. *d e d* is the cornea, which is a strong, horny, and delicately-transparent coat. Immediately behind the cornea, and

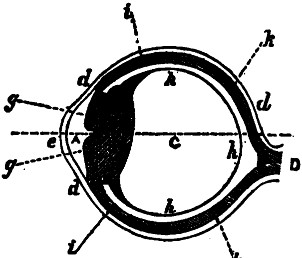


FIG. 22.

in contact with it, is the first refractive medium, called the *aqueous humour*, which is found to consist of nearly pure water, holding a little chloride of sodium and gelatine in solution, with traces of albumen. Its refractive power is nearly the same as that of water, and parallel rays of light having the direction of the axis of the eye will, in consequence of the shape of the cornea, after deviation at the surface of this humour, converge accurately to a point. At the posterior surface of the chamber A, in contact with the aqueous humour, is the iris, *g g*, which is a circular opaque diaphragm, consisting of muscular fibres, by whose contraction or expansion an aperture in the centre, called the *pupil*, is diminished or increased according to the supply of light. The object of the pupil is to moderate the illumination of the image on the retina. The iris is seen through the cornea, and gives the eye its colour.

In a small bag or capsule immediately behind the iris, and in contact with it, closing up the pupil, and completing the chamber of the aqueous

humour, lies the *crystalline humour*, B. It is a double convex lens of unequal curvature. Its density towards the axis is found to be greater than at the edge, and this corrects the spherical aberration that would otherwise exist. It contains a much larger portion of albumen and gelatine than the other humours. The posterior chamber, C, of the eye is filled with the *vitreous humour*, whose composition and specific gravity are nearly the same as the aqueous humour. At the final focus of parallel rays deviated by these humours, and constituting the inner surface of the chamber, C, is the retina, *h h h*, which is a network of nerves of extreme delicacy, all proceeding from one great branch, D, called the *optic nerve*, that enters the eye obliquely towards the nose. The retina lines the whole of the chamber C, except where the crystalline humour commences at *i i*. Just behind the retina is the choroid coat, *k k*, covered with a very black velvety pigment, upon which the nerves of the retina rest. The office of this pigment is to absorb the light which enters the eye, as soon as it has excited the retina, thus preventing internal reflection, and consequent confusion of vision. The last in order is *d d d*, the *sclerotic coat*, which is a thick, tough envelope, uniting with the cornea at *d d*, and constituting what is called the white of the eye. It is to this coating that the muscles are attached which give motion to the eye.

From a little careful reflection on the structure of the eye it will be obvious that inverted images of external objects are formed on the retina. This may be easily seen by removing the posterior coating of the eye of any recently killed animal, and exposing the retina and choroid coating from behind. The distinctness of these images, and our perceptions of the objects from which they arise, must depend upon the distance

of the retina from the crystalline lens. The habitual position of the retina in a perfect eye is nearly at the focus for parallel rays deviated by all the humours, because the diameter of the pupil is so small compared with the distance of objects at which we ordinarily look, that the rays constituting the formation of images may be regarded as parallel. With age the cornea loses a portion of its convexity, and the power of the eye is diminished, and distinct images are no longer formed on the retina, the rays tending to focus behind it. Persons possessing such eyes are said to be long-sighted, because they see objects better at a distance, and this defect is remedied by convex glasses, which restore the lost power, and with it the distinct vision. The opposite defect, arising from too great convexity, is also very common, especially among young people. The power of the eye being too great, the image is formed in the vitreous humour in front of the retina, and the remedy is found in the use of concave glasses.

The fact that images are formed in an inverted position on the retina of the eye, and yet we see these objects erect, has at various times given rise to a good deal of discussion. It is thought that the solution of the difficulty is to be found in the fact that we look at the objects and not their images.

Analysis of Light.—We have assumed that light is a simple substance, and that all the rays are refracted in precisely the same manner, and therefore suffer the same changes when acted upon by the same media. This is not, however, its constitution. White light, as coming from the sun, or any luminous body, is composed of seven different colours, viz., red, orange, yellow, green, blue, indigo, violet. These colours are called the primary colours, since by the mix-

ture of some two or more of them all other colours are produced.

The decomposition of white light, or its separation into the primary colours, is effected by means of a prism. When a ray of white light is admitted through a small hole in the shutter of a darkened room, and falls upon a horizontal prism, the rays are refracted, and form on the wall or a screen the seven beams of colour just mentioned. The elongated image on the screen is called the solar spectrum, and the following is the order of the coloured rays :—

Violet,
Indigo,
Blue,
Green,
Yellow,
Orange,
Red.

This separation of white light depends entirely upon the difference in their refrangibility in passing through the prism. Those which are refracted least are at the lowest part of the spectrum, and those most at the upper part. The red rays are the least refracted, and the violet the most. If, by means of a convex lens, these coloured beams of light be collected and converged to a focus, they will form white light.

Besides these coloured rays, there is an invisible space below the red where the heat is greater than at any other part of the spectrum, and a space above the violet where the chemical effect is greater. These invisible rays below the red are called *heat rays*, and those above the violet are called *actinic rays*.

The greatest illuminating power is in the middle

rays. A thermometer and a slip of paper prepared with nitrate of silver will show these points on the spectrum.

If a circular disc be painted in sections with the prismatic colours in the order in which they appear on the spectrum, it will be seen that on turning the disc rapidly by a piece of mechanism the separate colours will blend into a greyish white.

The natural colour of a body depends on the nature and arrangement of the particles of matter of which it is composed, and not on any inherent quality of the object itself. When a ray of light falls on a body which is not transparent, it will reflect certain rays of light from its surface, and of course appear of the colour of the light it reflects. A body appears red because it reflects the red rays of light to the eye, and so with the other colours. Some bodies do not reflect one colour more than another, but reflect or absorb them all equally. Such are called neutral or colourless bodies. Those which reflect all the rays are white. Those which absorb all the rays are black. By changing the molecular arrangement of a body the colour may also be changed. Frequent illustrations of this kind occur in chemical experiments. Any two colours which combine to produce white light are called complementary colours.

If a coloured wafer be fastened on a sheet of white paper, and the eye fixed steadily upon it, a ring of coloured light will, when the eye becomes fatigued, play round the wafer, and this colour will be the complementary colour of the wafer. If the wafer is red the ring will be green ; if the wafer is orange the ring will be blue. These rings of colour are called accidental. If we look steadily for some time at a coloured object on a white ground we shall observe it surrounded with a coloured fringe, whose colour will be

complementary to the colour of the object. As a general rule, colours will appear to the best advantage when they are complementary to each other. In arranging flowers in a garden or bouquet blue will look best with orange, and violet next to yellow. White, red, and pink should be surrounded with green leaves or white flowers. When colours are grouped which are not complementary, the effect on the eye is similar to that of a discord on a musical instrument on the ear.

The Rainbow. — The rainbow is a brilliantly coloured arc of seven different colours, generally exhibited upon the clouds opposite the sun during the

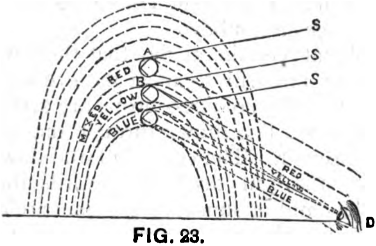


FIG. 23.

occurrence of rain and sunshine. The rainbow is produced by the refraction and reflection of the solar rays in drops of falling rain. A rainbow may also be formed by the sun shining on drops of water falling from a fountain or waterfall. The rays of light proceeding from the sun fall upon the spherical drops of rain and undergo refraction, and are internally reflected, and then emerge into the atmosphere and undergo a second refraction. The result is that the emergent rays are resolved into the prismatic colours, which, reaching the eye from different drops, give rise to the colours which are observed. Let A B C (*Fig.* 23) be

three drops of rain, S A, S B, S C three rays of the sun. The ray S A, by refraction, is divided into three colours—the blue and yellow are bent above the eye at D, and the red enters it. The ray S B is divided into three colours—the blue is bent above, and the red falls below the eye, while the yellow enters it. The ray S C is also divided into three colours—the blue, which is bent most, enters the eye, and the other two fall below it. Thus the eye sees the blue at C, and of all drops in the position of C, the yellow at B, and the red at A ; and the same may also be inferred respecting the other four colours of the spectrum: each drop sends a different colour to the eye, and thus the eye sees a rainbow.

It is only at certain angles that the rays emerge with sufficient intensity to affect the eye with colours. Hence it is that the coloured drops are arranged symmetrically about a line drawn through the sun and the eye of an observer. The centre of the bow is in this line, and as the sun declines towards the horizon the bow rises, and at sunset it is a semicircle.

We have seen that the rays of light differ greatly in refrangibility. Only a single and different coloured ray from each drop will reach the eye of the spectator; but as in a shower there is a succession of drops in all positions relative to the eye, the eye is enabled to receive the different coloured rays refracted at different inclinations. Two rainbows are not unfrequently observed at the same time, the one exterior and less strongly marked than the other. The inner arch, which is the brightest, is the *primary bow;* the outer arch, in which the colours are reversed, is called the *secondary bow.* This bow is formed by light which enters the drops, and being refracted, is twice internally reflected, and then emerges, being again refracted. As

no two persons can occupy exactly the same position, it is quite clear that no two can see the same colour reflected from the same drop, and consequently no two persons can see the same rainbow.

The beautiful crimson colour of the clouds after sunset is mainly due to the fact that the red rays of solar light are less refrangible than any of the other colours, and in consequence of this they are not bent out of their course like the blue and yellow, and are therefore the last to disappear; and for the same reason they are the first to appear in the morning, and give the clouds their crimson colour.

Double refraction is a property which some bodies possess of causing a ray of light, in passing through them, to undergo two refractions; that is, a single ray is divided into two rays. Iceland spar possesses this power in a remarkable degree. That the phenomenon of double refraction is due entirely to the molecular structure of the medium through which the light passes, is proved by taking a cube of regularly annealed glass, which produces but one refracted ray; but on heating the glass, and subjecting it to pressure, a change is effected in the molecular arrangement of the parts, and double refraction takes place. In *Fig.* 24, let S T represent a ray of light falling on the surface of a crystal of Iceland spar, A D E C, in a perpendicular direction. Instead of passing through without any refraction, as it would if it had fallen perpendicularly on the surface of a piece of glass, the ray S T is divided into two separate rays—the one, T O, in the direction of the original ray; the other, T E, being refracted.

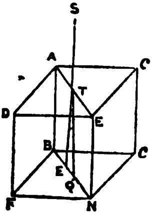


FIG. 24.

The first of these rays, or the one which follows the ordinary law of refraction, is the ordinary ray; the other the extraordinary ray. If we look at a small object, such as a letter, through a plate of glass, it appears single, but if a plate of Iceland spar be substituted a double letter will be seen.

Polarized Light.—When a ray of light has been reflected from the surface of a body under certain special conditions, or transmitted through a thin plate of tourmaline, it undergoes a remarkable change in its properties, so that it is no longer reflected and refracted as before. The effect thus produced upon it is called polarization, and the rays of light thus affected are said to be polarized. Light is also polarized by reflection from many substances, such as glass, water, ebony, air, mother of pearl, and the surfaces of crystals, provided that the light fall at a certain angle peculiar to each substance, and this angle is called the polarizing angle.

Optical Instruments.—A telescope is an instrument for viewing distant objects. Telescopes may be divided into two kinds—*refracting telescopes* and *reflecting telescopes*: In refracting telescopes a lens, usually called the object glass, is employed to form an image. In reflecting telescopes a mirror or speculum is used for the same purpose. In both, the image formed is seen by a lens or a combination of lenses called the eyepiece. The method of arranging these parts, together with the auxiliary pieces, determines the particular kind of telescope.

A refracting telescope consists essentially of two convex lenses, the object glass and the eyeglass. An inverted image of a star or other distant object is produced by the object glass and magnified by the eyeglass.

Fig. 25 represents the arrangement of the glasses in

an astronomical telescope. B is the object glass, at the end of the tube, which collects the rays proceeding from a distant object, and forms an inverted image at o′ o′ in the focus of the eyeglass G; by this the image is magnified, and viewed by the eye at E.

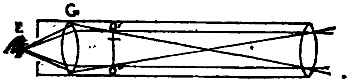


FIG. 25.

A terrestrial telescope differs from an astronomical telescope by having two additional convex lenses, which together constitute what is called an erecting piece, which enables the observer to see images erect instead of inverted.

The Galilean telescope is so called from its inventor Galileo. It is, in fact, a common opera glass, which consists of a convex object glass and a double concave eyeglass. *Fig.* 26 represents this kind of

FIG. 26.

telescope, where O is a single convex object glass, in the focus of which an inverted image of the object would be formed were it not for the double concave lens E. The converging rays of light are caused to diverge by falling on this lens, and enter the eye parallel, and form an erect image of the object.

A reflecting telescope is one in which the image of a distant object is formed by means of a polished metal reflector or speculum, which image is then viewed with an eyeglass. The eyepiece may either be a single lens or a combination of lenses. One of these

telescopes was constructed by Newton (*Fig.* 27). It consists of a concave speculum, A A, placed at one end of the tube, and a small plane mirror, C D, placed ob-

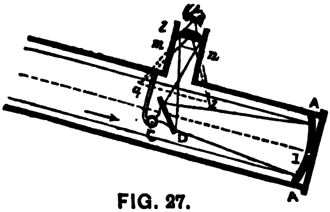


FIG. 27.

liquely to the axis of the tube. The image of a distant object formed by the speculum A A is reflected by the mirror C D to a point, *m n*, on the side of the tube, and is there seen through an eyepiece, *l*, which is made of two plano-convex lenses. Large reflecting telescopes are now constructed without the small plane mirror C D. This is accomplished by inclining the speculum A A so as to throw the image on one side, where it is viewed by an eyeglass.

A microscope is a modification of a telescope, and is used for viewing near objects. Microscopes

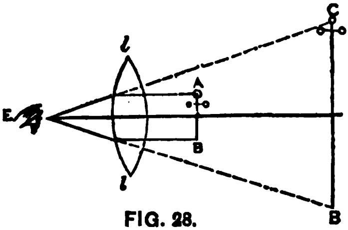


FIG. 28.

are either simple or compound. The simple microscope consists of a double convex lens of short focal

distance. It is usually set in a frame of horn or metal, and held in the hand. It is, in fact, a simple magnifying glass. *Fig.* 28 represents the magnifying principle of the microscope. An eye at E would see the cross A B under the visual angle; but when the lens *l l* is interposed it is seen under the visual angle C E B and therefore appears much enlarged, as shown at C B.

The compound microscope consists essentially of a double convex lens, called the *object lens*, and a second double convex lens, called the *eyeglass*. *Fig.* 29 shows a section of this instrument. The object to be observed is placed at *a* between two plates of glass, on a support. Over this is a tube, in which are placed the two lenses,—the object lens, *l*, at the lower end, and the eyepiece, L, at its upper extremity. The object, *a*, being placed a little beyond the principal focus of the object glass, this lens produces a real image, *b c*, which is inverted. The object glass is so placed that its principal focus is a little beyond the image *b c*. This lens then acts as a simple microscope, and magnifies the image as if it were seen at C D. The magnifying power depends on the object lens. This power may be greatly increased by combining several lenses. A second lens is often added to the eyepiece, for the purpose of remedying the defect arising from spherical aberration, and all the lenses are achromatic. The object, when transparent, is illuminated by a mirror, M, which concentrates the rays upon it. When the object is opaque it is illuminated by a lens which projects from the side

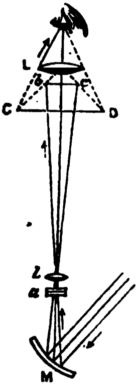


FIG. 29.

and concentrates the rays upon it. The magnifying power depends on the object lens, and may be increased by combining two or three lenses.

The stereoscope is an apparatus employed to give flat pictures the appearance of standing in relief. It was invented by Wheatstone and improved by Brewster. When we look at an object with both eyes, each eye sees a different portion of it. If we look at a small cube first with one eye, then with the other, without moving the head, we shall see the perspective of the cube different in the two cases, and the nearer the cube the more apparent it will be. If the cube has one side directly in front of the observer and the right eye is closed, the other eye will see the front face and also the left-hand face, but not the right. If, however, the left eye is closed, the other eye will see the front face and also the right-hand face, but not the left. Hence we know that the two images formed by the two eyes are not absolutely alike. It is the difference of images which gives the idea of relief in looking at a solid body. If we suppose two pictures of any object painted on a flat surface, the one picture as it would appear to the right eye and the other as it would appear to the left, and then look at these pictures with both eyes through lenses which cause the pictures to coincide, the impression is precisely the same as if the object itself were before the eyes. The illusion is so complete that it is difficult to imagine we are looking at pictures on a flat surface. *Fig.* 30 shows the course of the rays in this instrument.

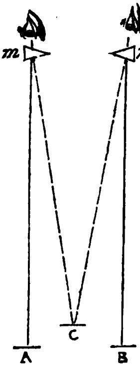


FIG. 30.

A represents a picture of the object as it would be seen by the right eye alone, B a picture of the same object as it would be seen by the left eye alone. *m n* are lenses which deviate the rays so as to make the pictures appear coincident at C. The lenses *m* and *n* should be perfectly symmetrical, and this was attained by Brewster by cutting a double convex lens in two, placing the right-hand half before the left eye and the left-hand half before the right eye.

RÉSUMÉ.

Distinct vision can only take place when the cornea and crystalline lens of the eye are of such convexities as to bring the rays of light proceeding from an object to an exact focus on the retina.

In a near-sighted person the curvature of the cornea and crystalline lens is so great that the rays of light are brought to a focus in front of the retina. The object is therefore not distinctly seen. This is remedied either by holding the object nearer to the eye, or the use of spectacles with concave glasses.

In a long-sighted person the cornea and crystalline lens is less curved, or flattened, and the rays of light do not converge sufficiently to form an image on the retina, but at a point behind it. This is remedied by the use of spectacles with convex glasses. Persons at advanced age usually require these spectacles. As the physical organization of the body declines, the humours of the eye dry up or are absorbed, and the cornea and crystalline lens shrink and become flattened.

Decomposition of Light.—When a ray of solar light passes through a prism it is decomposed into the seven prismatic colours. These seven colours may be reunited, so as to produce white light. The separation of these rays is called dispersion.

Refraction.—When a ray of light, in passing from one medium to another, deviates from a straight line, it is said to be refracted.

Double Refraction.—A ray of light is doubly refracted when it falls on any transparent body and is separated into two rays, the ordinary ray and the extraordinary ray.

Polarized Light.—If a reflected ray of light, under certain conditions, is made to pass through transparent crystals, it is no longer refracted and reflected as before. The effect thus produced is called polarization, and the rays of light so affected are said to be polarized. This phenomenon was first noticed by Malus, an engineer officer, of Paris.

A telescope is an instrument for magnifying and rendering distant objects visible.

In a refracting telescope an image is formed by a convex object glass, and the image is viewed by a lens or a combination of lenses called the eyepiece.

In a reflecting telescope the image of a distant object is formed by means of a concave mirror at the end of the tube. This reflector would form an image at the other end of the tube, but the rays are intercepted by a small mirror or prism, so inclined that the rays are totally reflected. The image is then viewed by means of the eyepiece.

A simple microscope is merely a magnifying glass formed by a double convex lens, and usually set in a frame of horn or metal.

A compound microscope consists of two convex lenses, so arranged that the second lens magnifies the image formed by the first lens, which acts as a simple microscope. In this manner the image of the object and not the object is examined.

HEAT.

Heat is known only by its effects on matter. In ordinary language the term heat is used to express the sensation of warmth, and absence of heat constitutes cold.

Two theories have been advanced to explain the phenomena of heat.

The first theory supposes heat to be a fluid without weight, and capable of passing freely from one body to another. The particles of this fluid repel each other, and are attracted by the particles of other bodies. This is called *the emission theory.* According to the second theory, heat consists of the vibratory motion of the particles of bodies, which motion is transmitted from one body to another through an elastic fluid, called ether, in a manner precisely the same as sound is transmitted through the air. The warmest bodies are those in which the vibrations are most rapid and most extensive. This is *the undulatory theory of heat.* According to the first theory a body cools by losing a portion of the fluid; according to the second theory it loses a part of its vibratory motion.

All bodies expand by heat, but in different degrees. The most dilatable bodies are gases, then liquids, then solids. In fluids we speak of an increase of volume, but in solids we distinguish two kinds of expansion,—linear expansion, or dilatation, and expansion of volume.

Linear Expansion.—If we wish to compare the rate of linear dilatation of different bodies we must take for a term of comparison the expansion experienced by a unit of length of each body when heated

from 32° to 33° F., and this is called the coefficient of linear expansion. The coefficients of linear expansion on many bodies were determined by Lavoisier in the following way:—The substance to be experimented on was reduced to the form of an uniform bar. It was then exposed for some time to the temperature of melting ice, and its exact length measured. The bar was then exposed to boiling water, and its exact length again measured. The increased length, divided by 180, gave the increase in length of the whole bar for 1° F. This result, divided by the length of the bar at 32° F., gave the linear expansion of a unit of length for an increase of temperature of 1° F., that is, *the coefficient of linear expansion.*

The coefficient of expansion in volume is the increase which a cubic unit of the substance undergoes when its temperature is raised 1° F. This coefficient may be found experimentally, or by multiplying its coefficient of linear dilatation by 3. For although the coefficients vary with different bodies for the same body, the coefficient of cubical expansion is three times that of linear expansion.

Suppose a rectangular prismatic bar, whose length, breadth, and thickness are a b c, its contents will bear a certain ratio to a^3. If it be expanded it will bear the same ratio to the cube of the side corresponding to a, for all parts expand proportionally. Hence if h be the linear dilatation of a, the new length will be $a + h$, and the ratio of the contents or volumes will be $a^3 : (a + h)^3$. The measure of linear dilatation is then $\frac{(a + h) - a}{a}$, and of cubical expansion $\frac{(a + h)^3 - a^3}{a^3}$; the first equal to $\frac{h}{a}$, and the second

to $\frac{3a^2h + 3ah^2 + h^3}{a^3}$ or to $\frac{3h}{a} + \frac{3h^2}{a^2} + \frac{h^3}{a^3}$. In all cases of solid expansion $\frac{h}{a}$ the linear dilatation is a very small fraction. Thus, for Falmouth tin, heated from 32° F. to 212° F., it is only $\frac{1}{462}$. The ratio of cubical expansion to linear dilatation, which is $\left(\frac{3h}{a} + \frac{3h^2}{a^2} + \frac{h^3}{a^3}\right) \div \frac{h}{a}$, or $3 + 3\frac{h}{a} + \frac{h^2}{a^2}$, differs very little from 3, and we may safely take this rule, when not requiring an exactness within $\frac{1}{150}$ of the whole quantity measured, that the cubical expansion may be found by trebling the linear dilatation.

The following table shows the increase in length of bars of different substances in rising from the temperature of freezing to that of boiling water :—

1000·000 in length of	glass tube becomes	at 212° F.	1000·861
,,	,,	crown glass	1000·875
,,	,,	platinum	1000·856
,,	,,	steel	1001·189
,,	,,	bismuth	1001·392
,,	,,	gold	1001·460
,,	,,	copper	1001·712
,,	,,	silver	1001·890
,,	,,	zinc	1002·942

The following increase of bulk, by the same elevation of temperature, has been ascertained :—

1000 parts of	water become	1046
,,	alcohol	1110
,,	fixed oil	1080
,,	ether	1070
,,	turpentine	1070
,,	mercury	1018

Gaseous bodies expand equally for equal increments of temperature. 1,000 parts of air at 32° F. become 1,375 at 212° F., and the same expansion is experienced by other aëriform bodies. The ratio of the expansion of gases has recently been corrected by Rudberg, and according to his investigation, one volume of gas at 32° F. becomes 1,365 at 212° F., so that a gas dilates $\frac{1}{493}$ of its bulk at 32° F. for each degree of Fahrenheit's thermometer, instead of $\frac{1}{480}$, as generally given. If the volume of a gas at zero be 1, its bulk at any higher temperature may be found by the following formula :—

$$\text{Vol. } 1 + \frac{\text{Temperature by Fahrenheit's thermometer.}}{461}$$

For if the expansion be expressed in parts of the bulk at 0° instead of 32° the expansion is $\frac{1}{461}$ for each additional degree of temperature.

A number of simple experiments can be performed to illustrate the expansion of bodies by heat.

Communication of Heat.—Heat may be communicated in three ways—by conduction, by convection, and by radiation.

Conductibility is that property of bodies by virtue of which they transmit heat. Those which transmit heat readily are called good conductors; those which do not transmit heat so readily are called bad conductors.

Ingenhousz showed that solid bodies possessed different degrees of conductibility by coating different rods of metal, marble, wood, and glass with soft wax that would melt at 140° F. These rods were placed in tubes with their open ends outward, the remaining portion of the tubes being immersed in a vessel filled with boiling water. Upon some of the rods the wax melted rapidly; upon some, more slowly;

and on others, not at all. If equal cubes of ivory, marble, glass, and the metals be heated by the same source, and thermometers placed on these cubes, we shall find the thermometers on the metals will rise first and those on the ivory and glass last. As a general rule, the most dense bodies conduct heat best. Spongy, light bodies, such as wool, silk, cotton, fur, and eider down, are bad conductors. This explains their use as articles of clothing in winter. We experience the sensation of warmth not by their communicating heat to the body, but by preventing the heat, from their bad conducting power, escaping readily into the air. This power of preventing the transmission of heat seems owing to the air they enclose; for on twisting these bodies their conducting power is greatly increased. Solids conduct heat much more readily than liquids. The rapidity with which silver conducts heat may be illustrated by wrapping a piece of muslin round a table spoon filled with water. If the spoon be introduced into the flame of a candle or lamp the water will boil without burning the muslin. The following table shows the conducting power of different solid bodies:—

Gold	1000
Platinum	981
Silver	973
Copper	898·2
Iron	374·3
Zinc	363
Tin	303·9
Lead	179·6
Marble	23·6
Porcelain	12·2
Clay	11·4

Convection.—Liquids conduct heat very slowly. If a piece of ice be placed at the bottom of a test-tube of moderate length, and water poured on the top of the ice, the water may be made to boil, by holding the upper part of the tube in the flame of a lamp, without melting the ice. Or if some ether be poured on the surface of a large basin filled with water and inflamed, it will burn for some time without sensibly affecting a thermometer immersed at a small depth below the surface of the water. When a blacksmith plunges a red-hot bar into water, the water becomes boiling hot immediately in contact with the iron bar, but the water not immediately in contact remains at the same temperature as it was before the bar was introduced.

If, however, we apply heat to the lower part of a vessel (*Fig.* 31) containing any liquid, it soon shows an increase of temperature. The liquid is heated by the transportation of its particles in quick succession. In this case the particles nearest to the source of heat become heated, and therefore specifically lighter, and ascend through the fluid, to which they impart a portion of their heat, while their place is supplied by another series of particles, which become heated and ascend in like manner; and this succession of rapid changes continues to take place until the whole mass of the fluid is raised to 212° F., the boiling point. These motions may be rendered visible by placing in a Florence flask, heated by a spirit

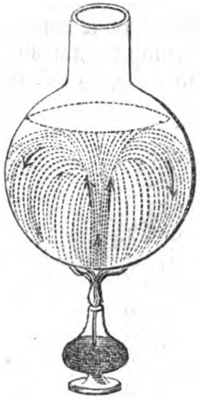


FIG. 31.

lamp, a few pieces of solid litmus. The coloured fluid will be seen to rise up the centre of the flask and descend down its sides. The process of cooling in a liquid is exactly the reverse of that just described. The particles at the surface, by contact with the air, lose a portion of their heat, become heavier, and sink to the bottom; their place is supplied by lighter particles rising from below, and in frosty weather this circulation goes on until the water acquires its maximum density at 38·75° F., and at a few degrees lower ice begins to form at the surface. The general law of expansion by heat and contraction by cold is all but universal; but there is, however, a remarkable exception to this law, attended with the most beneficial results. Water, in passing from a liquid to a solid state, increases in volume, and iron also, at the moment of solidification, increases in bulk. The expansion of water by cold commences, as we have just stated, a few degrees above the point of congelation, and this expansion increases in an increasing ratio, until the particles assume a definite crystalline form, and a sheet of ice is formed at the surface. If, like oil, mercury, and other liquids, the density of water went on augmenting till it sank to 32° F., it would then suddenly become a solid block of ice, and every living animal within it would perish, and in this climate a river so frozen could never again be liquefied, because the process of thawing would commence at the surface, and the heated and lighter particles would remain there, and prevent the convection of heat to the lower strata. Every particle of solid ice which covers the frozen lakes of the north has been fixed according to the law just described. "Nature lays her beams in music, and it is the function of science to purify our senses, so as to enable us to hear the strain." The conducting power of gases also

F

varies. Hydrogen has the lowest conducting power, atmospheric air is considerably higher, and carbonic acid gas the highest. The conduction and diffusion of heat by the methods just described is a slow process, and is limited to bodies in immediate contact with each other; but heat may be diffused among bodies not in contact by radiation.

Radiation.—A heated iron ball in vacuo emits its heat in all directions; and in air, although a portion of the heat passes off by convection, still we may regard it as propagated through space in straight lines. All bodies radiate heat, but not equally well. The radiation is in proportion to the roughness of the radiating surface. All dull and dark surfaces are, for the most part, good radiators, but bright and polished surfaces are generally bad radiators.

If a metal surface be scratched or made rough its radiating power is greatly increased. Water in a highly polished metal pot will retain its heat much longer than in one that is black and dull. Leslie procured a cubical vessel of block tin: one side was polished, the second was made rough by scraping, the third he covered with a glass plate, and the fourth he blackened with lampblack. He then filled the vessel with boiling water, and presented the different sides in succession to a delicate air thermometer, preserving the same distance in each case. He found the polished surface radiated least, and the surface covered with lampblack radiated most.

The radiation of heat is not confined to incandescent bodies, like the candle or the sun or burning coal; but this radiation of heat goes on at all times, and from all surfaces, whether their temperature be the same or different from that of surrounding objects. The temperature of a body, therefore, falls when it radiates more

heat than it absorbs. Its temperature is uniform when it absorbs and radiates the same amount. When the absorption exceeds the radiation it grows warmer. All bodies tend to a uniform temperature, although this condition is never fully realized. Bodies nearest the outer walls of a room, or another apartment, will be influenced by continually exchanging their heat with the walls and the walls with the atmosphere, and this will exert some influence on the temperature of bodies in the room.

The Formation of Dew.—Dew is the moisture of the air condensed by coming in contact with bodies colder than itself. The temperature at which this condensation takes place is indicated on the thermometer as the dew-point. This point is by no means constant, since dew is only deposited when the air is saturated with moisture, and the moisture required for the saturation of air at a high temperature is much greater than at low temperatures. If the saturation is complete, the least fall of temperature is sufficient for the formation of dew; but if the air be dry, then a body must be several degrees colder before moisture is deposited on its surface. Dew may be produced by bringing a tumbler of cold water into a warm room. The sides of the glass cool the surrounding air that it can no longer retain its moisture, or, in other words, the temperature of the air is reduced below the dew-point. In the same manner moisture is formed on the windows of a heated room, if the temperature outside is low enough to sufficiently cool the glass. The true theory of dew was first established by Dr. Wells. According to his theory the earth and plants become cooled by the radiation of heat, thus producing a deposit of moisture from the stratum of air in contact with these surfaces. Good radiators are soonest covered with dew, whilst

bad radiators have little or no dew deposited on them.

The state of the atmosphere, as we have just seen, greatly influences the amount of dew. When the air is clear the dew is abundant; when cloudy, little or no dew is formed. In this case the clouds radiate heat to the earth, and this prevents the earth from cooling so rapidly. A strong wind prevents the formation of dew by removing the strata of air next the earth before they have time to be cooled down to the point of saturation, or the dew-point. A gentle breeze may, in some cases, facilitate the formation of dew by replacing the layer of air from which the moisture has been deposited by another which contains more moisture. WHITE FROST is frozen dew. As all bodies have not the same capacity for radiating heat, and as some cool more rapidly than others, it follows that with the same exposure on a summer's night some bodies will be densely covered with dew, while others remain perfectly dry.

Reflection of Heat.—A ray of heat radiated from the surface of a body proceeds in straight lines until it meets some reflecting surface, when it is thrown off according to the law that the angle of incidence is equal to the angle of reflection. A concave mirror is a reflecting surface curved towards the source of heat. For experimental purposes they are generally parabolic in shape. It is a property of such mirrors that all rays which before incidence are parallel to the axis, after reflection converge to a single point, which point is the focus of the mirror; and conversely, if the rays radiate from the focus, they will be reflected in lines parallel to the axis.

Let *Fig.* 32 represent two parabolic reflectors, having their axes coincident, and their surfaces

turned to each other. In the focus N of the mirror is placed a red-hot iron ball, and in the focus M of the mirror is placed a piece of phosphorus. The heat radiating from the ball is reflected from the

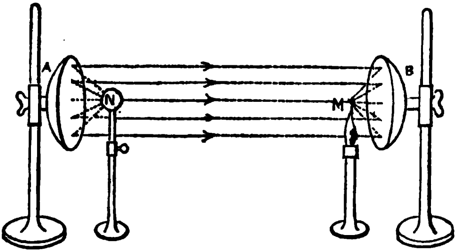


FIG. 32.

reflector A, falls on the surface of the reflector B, is again reflected to the focus M, and the heat concentrated is sufficient to inflame the phosphorus, even when the reflectors are several yards distant from each other. If only the reflector A was used the phosphorus could not be ignited. With a parabolic reflector the rays of the sun can be so concentrated as to ignite inflammable substances. A differential thermometer may, for some experiments, be placed in the focus M instead of the phosphorus.

Reflecting Power of Different Bodies.—Those bodies which reflect a large portion of the incident heat are called good reflectors; those which reflect but little incident heat are called bad reflectors. Good reflectors are bad absorbers, and bad reflectors are good absorbers. Leslie's apparatus for determining the relative reflecting powers of different bodies consists of a cubical tin box filled with water at the boiling point, and placed in front of a parabolic reflector. The rays of heat falling on the reflector A are reflected, and

tend to come to a focus at N; but by interposing a square plate of some substance between the reflector A and its focus, the rays are again reflected, and come to a focus between the plate and the front of the reflector. The heat so reflected is received on a differential thermometer, by which it is measured. By interposing plates of different substances in succession their relative reflecting powers are determined. In this experiment only one reflector is used.

The Compensating Pendulum.—The construction of the compensating pendulum depends on the principle of the expansion and contraction of metals. We have seen in *Mechanical Physics*, page 90, that the time of oscillation of a pendulum depends on its length, vibrating faster when shortened and slower when lengthened. If a pendulum were constructed with a single metallic rod, its rate of vibration would be constantly changing with every alteration of temperature. To obviate this, and secure uniformity of vibration, the gridiron pendulum of Harrison was constructed.

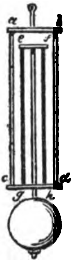


FIG. 33.

It consists of five parallel bars of metal, arranged as shown in *Fig.* 33. The bars *a c b d*, and the centre bar, are steel, and when they expand the effect is to lengthen the pendulum. The centre bar passes through the cross bar *g h*, and is firmly secured to the bar *e f*. The bars shown by the dark lines are of brass, firmly secured to both of the cross pieces. When they expand, the effect is to raise *e f*, and thus shorten the pendulum. If these pieces are properly adjusted, the amount of shortening is exactly equal to the amount of lengthening, and as these balance each other, the pendulum remains invariable. There is another form of compensating pendulum, called the

Mercurial Pendulum, which consists of a steel frame attached to a cylindrical glass vessel containing mercury. In warm weather the steel frame expands, and thus increases the length of the pendulum and lowers the centre of oscillation; but at the same time the mercury expands and rises upwards, and by a proper adjustment the centre of oscillation rises upward as far as it is carried downward, or, in other words, the expansion in both directions is equal, and the vibrations remain unaltered.

RÉSUMÉ.

Heat is a sensation known by its effects on matter.

Two theories—the emission theory and the undulatory theory.

One of the common effects of heat is to enlarge the bulk of bodies.

In solid bodies two kinds of expansion are distinguished—linear dilatation, or expansion of length, and cubical dilatation, or expansion of volume.

The coefficient of linear dilatation is the increase in the length of a body when the temperature rises from zero to 1 degree. $l' = l(1 + nt)$.

The coefficient of cubical dilatation is the increase of the unit of volume under the same circumstances.

Heat may be communicated to bodies in three ways—by conduction, by convection, and by radiation.

Dew is formed by the condensation of the aqueous vapour of the atmosphere. It is occasioned by the lowering of temperature which bodies experience in consequence of the radiation of their heat.

When heat rays fall on a body they are divided into

two parts; one of which penetrates the body, the other is repelled from the surface like an elastic ball. This is said to be reflected. The laws are—1st. The angle of reflection is equal to the angle of incidence; 2nd. Both the incident and reflected rays are in the same plane with the normal to the reflecting surface. The reflecting power of a body is its power of throwing off the incident heat, and this power varies with different bodies. The absorbing power of a body is always inversely as its reflecting power.

The compensating pendulum is a pendulum so constructed that the elongation when the temperature rises is so compensated that the distance between the centre of oscillation and suspension remains constant.

Specific Heat.—Different substances require different degrees of heat to raise them to the same temperature. This is called specific heat.

If 1 lb. of water at 100° be mixed with 1 lb. at 40°, the mean temperature will be $\frac{100° + 40°}{2} = 70°$.

In the same way, the mean temperature of the same liquids may be found when mixed together,—oil $\frac{80 + 20}{2} = 50°$; mercury $\frac{140 + 40}{2} = 90°$.

But if 1 lb. of water at 100° be mixed with 1 lb. of olive oil at 40°, we shall not have the mean temperature of 70° but 80°. In the same way, if 1 lb. of mercury at 40° be mixed with 1 lb. of water at 100°, we shall have a temperature of 98°. Now, the water parted with 20° of heat in the case of oil, which was sufficient to raise its temperature 40°, that is, from 40° to 80°. In the case of the mercury, the water parted with only

2°, which was sufficient to raise the mercury 58°, from 40° to 98°: equal weights of the liquids being taken in the experiment. From these experiments it appears that equal weights of water, oil, and mercury require different degrees of heat to raise them to the same temperature.

Solids may be easily experimented on. If 1 lb. of iron be taken and raised to a given temperature, and immersed in 1 lb. of water at a known temperature, we can easily determine the specific heat by the increase of temperature, the same as by mixing two liquids at a different temperature. Specific heat is generally taken with reference to equal weights rather than equal volumes. 1 lb. of water, in rising to a given temperature, requires or absorbs thirty times more heat than 1 lb. of mercury. If mercury be taken as 1, water will be 30. The great specific heat of water is very important: it rises in temperature slowly, and parts with its heat slowly, which tends to equalize the temperature of the air and earth. The small specific heat of mercury is useful. No relation exists in the table of specific heats when equal weights of different bodies are taken; but if *equivalent* weights be taken, then we have a relation. Let us take 16 oz. of sulphur, 28 of iron, 32 of phosphorus, 6 of carbon. Let these equivalent quantities be then raised to the temperature of 212°, and afterwards immersed in water at 60°, so as to observe how much each raises the temperature of the liquid. By such an experiment we shall find that 16 parts of sulphur and 28 of iron will raise the water to the same temperature, while the phosphorus will raise it four times higher. It thus appears that the specific heats of sulphur and iron, when taken in equivalent quantities, are the same, whilst phosphorus is four times greater.

If metal balls of iron, lead, bismuth, tin, and copper, be taken and raised to the same temperature, by immersing them in oil at 180° C., and after a few minutes we place them on a cake of beeswax, about 6 inches in diameter and half an inch thick, which is supported on the large ring of a retort stand, we shall find that the iron and copper melt their way through; then follow the tin, lead, and bismuth,—the latter having penetrated but a small distance. If we take as unity the amount of heat given out by a pound of water in falling through one degree of temperature, the following table of Professor Tyndall's will express the amount of heat given out by a pound weight of each of the following substances:—

Water	1·0000
Sulphur	0·2026
Arsenic	0·0814
Antimony	0·0508
Bismuth	0·0308
Zinc	0·0955
Cadmium	0·0567
Tin	0·0562
Lead	0·0314
Iron	0·1138
Cobalt	0·1070
Nickel	0·1086
Copper	0·0951
Silver	0·0570
Gold	0·0324
Platinum	0·0324

Latent Heat.—When any solid body is converted into a liquid, a large amount of heat is observed to enter it without raising its temperature. This heat

serves to liquefy the body without increasing its temperature. The water which flows from melting ice is no hotter than the ice; the heat it contains is not sensible, nor does it affect the thermometer; it is called latent heat. If a piece of ice be hung in a warm room it melts slowly. This would not be the case if a small amount of heat was only necessary to liquefy it. It gathers heat from surrounding objects, which is all expended in liquefying the body. If a cubic inch of ice be taken and a cubic inch of water, and the temperature of the water lowered to 32°, and the ice and water removed into a warm room, and a thermometer placed in the water, we shall be able to ascertain the amount of heat the water receives in a given time. Let us suppose the thermometer to rise 7° every half hour, and the time observed till the whole of the ice is melted. There will be 14° of heat added every hour: by these means we shall be able to ascertain how much heat disappears, or becomes latent, in converting the ice into water. It will take 10½ hours to liquefy the ice. The water in this experiment was only 40°, or 8 degrees above 32°. Now, if we multiply 7×21, we have $147 - 8 = 139$, the number of degrees of heat absorbed or rendered latent in converting the ice into water; in other words, 139° of heat have become latent. If we take 1 oz. of powdered ice or snow, and 1 oz. of water at 172°, the ice will be melted, and we shall have 2 oz. at 32°. The water lost 140° of heat, and the ice absorbed it; but if we take water at 32°, and water at 172°, we shall have the mean temperature of 102°. What we have said as regards ice, holds good with all solids: a certain amount of heat is in all cases rendered latent. The following table shows the latent heat of different bodies:—

Water	140°
Sulphur	145
Lead	162
Wax	175
Tin	500

When water freezes, the 140° of heat abandons it and manifests itself in a free or sensible state. If a flask of boiling water be saturated with the sulphate of soda, and the cork withdrawn and a rough body introduced, the soda will become solid, and the sudden conversion of the liquid into a solid causes it to part with its heat; if a thermometer be introduced the mercury in it will rise 30° or 40°: this is precisely what takes place in the freezing of water. Solids in becoming liquids render a large amount of heat latent, and liquids in becoming solids part with the heat previously rendered latent.

When solids are compelled to liquefy rapidly without a free supply of heat, the temperature of surrounding objects is lowered. Salt in water, or nitre, causes the thermometer to fall several degrees. If sulphate of soda and snow be mingled together the temperature falls to zero. Chloride of calcium mixed with snow, lowers the temperature so as to freeze mercury. These are called freezing mixtures.

Latent Heat of Gases.—It is not necessary for a liquid to boil in order to produce vaporization. The drying up of water by its gradual conversion into vapour is a phenomenon with which we are all familiar.

If water be raised to 212° it is converted into steam, but the steam is the same temperature as the water. If it were only necessary to raise water to 212° to convert it into vapour, it would, as soon as it

attained that temperature, explode into steam, like gunpowder. A cubic inch of water will make a cubic foot of steam. If vapours contained no more heat than the liquids, they would immediately condense into liquids as soon as they came in contact with any body lower in temperature; but it is found necessary to expose them to a great amount of cold. Ice in becoming water renders a large amount of heat latent; water in becoming steam also renders a large amount of heat latent: what occurs with water occurs with all liquids.

If a vessel filled with water at 32° be placed over a regular source of heat, and the time observed necessary to raise it to 212°, it will require five times longer before the water is entirely converted into steam. Now the water has been raised through a temperature of 180°, say in one half hour; we multiply 180 × 5, which is the number of hours taken, and we get 900°: yet the steam has only the temperature of 212°. What has become of this enormous amount of heat? It has been rendered latent in the steam, and this can be demonstrated by condensing the steam, and observing the amount of heat evolved. Let the steam be conducted into ice-cold water, and it will part with its latent heat, and raise the water to its boiling point. If 11 cubic inches of water be taken at 32°, and raised to 212° by the steam of 2 cubic inches of water, we shall have 13 cubic inches at 212°. 2 cubic inches of water, in the form of steam, have raised 11 cubic inches of water 180°, and the whole 13 cubic inches have a temperature of 212°. If a cubic foot of steam, at 212°, be contained in a close vessel, and 5½ inches of ice-cold water, at 32°, be injected into this vessel, we shall have 6½ cubic inches of water at 212°. Now it is evident that in returning

to a state of water the steam has given out sufficient heat to raise $5\frac{1}{2}$ cubic inches of water from $32°$ to $212°$. The heat which was latent in the steam has now been made sensible in raising the $5\frac{1}{2}$ cubic inches of water through $5\frac{1}{2}$ times $180°$ of heat, viz., $990°$.

The Thermometer.—A glass tube (*Fig.* 34) of uniform bore is taken, and one end blown into a bulb, in the blowpipe flame of a lamp. The bulb, when nicely formed, is carefully heated over the flame of a spirit lamp. This causes nearly all the air to be expelled. The open end of the tube is then placed in a vessel containing mercury. As the bulb cools, the pressure of the air on the surface of the mercury drives a portion of the fluid into the bulb. By applying heat so as to cause the mercury to boil, the remainder of the air is driven out. Heat is now applied till the column of mercury rises to the top; it is then hermetically sealed by the blowpipe. The contraction of the mercury leaves a vacuum in the upper part of the tube which is essential to the perfection of the instrument. It has now to be graduated. Two points are taken. The temperature of melting ice, or a mixture of ice and water (the freezing point of water and the melting point of ice is always constant): this constitutes the freezing point. The boiling point of water is always constant, regard being had to the height of the barometer when great accuracy is required: this constitutes the boiling point. These points are marked,

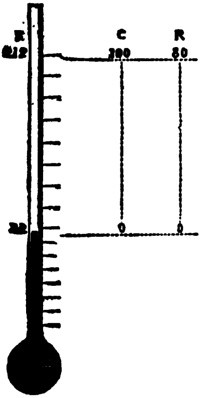


FIG. 34.

and the interval divided into degrees: the division is entirely arbitrary. In Europe and America the Centigrade scale is used; in England, the scale known as Fahrenheit's is employed. In the F. thermometer the interval between the freezing and boiling points is divided into 180°; in the Centigrade it is divided into 100°. In F. the temperature of ebullition is expressed at 212°. In Russia, Réaumur's scale is used, which commences at 1°, and the boiling point is at 80°.

A thermometer reveals to us the intensity of heat, not the quantity, for a test-tube of boiling water raises the mercury to the same point as a pailful, although the larger quantity must contain the most heat.

When directions are given to raise the temperature of a body to 110° it means that heat is to be added sufficient to raise the mercurial column to 110°.

To reduce the Degrees of a Thermometer in a Fahrenheit Scale to a Centigrade, and the converse.— To reduce a Fahrenheit to a Centigrade, subtract .32, which gives the number of degrees above the freezing point, and multiply by $\frac{5}{9}$, because 180° Fahrenheit are equal to 100° Centigrade. Thus, 59° F. = 27° F. above freezing, or 32° F. $= \frac{5 \times 27}{9} =$ 15° Centigrade.

To reduce Centigrade to Fahrenheit, multiply by $\frac{9}{5}$, which gives the number of degrees Fahrenheit above the freezing point, and add 32, which gives the number above Fahrenheit's zero. Thus, 60° Centigrade = 108° F. above freezing point = 108° F. + 32° F. = 140° F.

An alcohol thermometer acts on the same principle as the mercurial thermometer. The alcohol is coloured red with a little cochineal. Alcohol thermometers have to be graduated by experiments with a standard mercurial thermometer, because the alcohol does not expand regularly with an increase of tempera-

ture. An alcohol thermometer is more easily constructed than a mercurial thermometer. The glass bulb is heated until a portion of the air is expelled, and then the open end of the tube is plunged into a vessel containing coloured alcohol. As the air in the bulb cools, the pressure of the external air drives up a portion of the alcohol into the bulb. If this be boiled, the vapour of alcohol will expel the remainder of the air, and by dipping the open end of the tube once more into the alcohol the bulb is filled. The end of the tube is then hermetically sealed. In high temperatures the mercurial thermometer is alone capable of being used. The mercury does not boil till raised to 662° F., whilst alcohol boils at 174°. As mercury cannot be relied on for temperatures lower than 32° F., on account of irregularities in the rate of contraction, neither can an alcoholic thermometer be relied on for temperatures considerably lower than 174° F.

A differential thermometer consists of two bulbs of thin glass connected by a fine glass tube bent twice at right angles. On the frame is a scale parallel to the horizontal braneh of the connecting tube (*Fig.* 35). The o of the scale is at the middle point of the horizontal tube, and the graduations proceed from this in both directions. The bulbs and a large part of the connecting tube are filled with air. There is, however, a small drop of coloured fluid, which separates the air in the two extremities. The index is so constructed that it should be at the o of the scale when the temperature of the two bulbs is the same. When one bulb is heated more

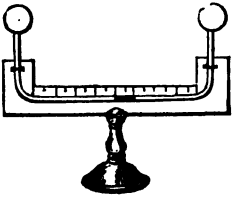


FIG. 35.

than the other, the air expands and drives the index towards the other bulb, until the tensions of the air in the two bulbs exactly balance each other.

Leslie's differential thermometer (*Fig.* 36) differs from the one just described in having bulbs smaller, and containing a longer column of liquid. The scales are placed by the sides of the vertical portions of the tube, having their o points at the middle of the vertical scales.

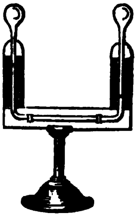


FIG. 36.

Pyrometer.—The measuring of higher temperatures than those indicated by the mercurial thermometer is of great importance in the arts, but this desirable object has not yet been fully accomplished. The most important thermometers are those of Brongneat and Wedgewood. The former is founded on the principle of the expansion of metals, and the latter on the diminution in the volume of clay at high temperatures; but these instruments are very unreliable, and there is yet wanted some accurate method of measuring temperatures above 600° F.

Ebullition, or boiling, is a rapid evaporation, in which the vapour escapes in the form of bubbles. In heating water the first bubbles which rise to the surface are due to the small quantities of air contained in the liquid, which expand and rise to the surface. As the heat is continued, particles of water are converted into vapour and rise through the liquid, becoming condensed by the colder layers of water above. When the whole volume of the liquid is properly heated, the bubbles are no longer condensed, but rise to the sur-

face and escape with a commotion which is called boiling, or ebullition.

The laws of ebullition have been determined, by experiment, as follows :—

1. The temperature of ebullition, or boiling point, increases with the pressure.

2. For a given pressure ebullition commences at a given temperature, which varies in different liquids, but which for equal pressures is always the same in the same liquid.

3. Whatever be the intensity of the source of heat, as soon as ebullition commences the temperature of the liquid remains stationary.

The principal causes which influence the boiling points of liquids are the presence of foreign matter, variations of pressure, and the nature of the vessels in which the boiling takes place. Matter in solution generally raises the boiling point of liquids. A solution of salt does not boil so readily as pure water. If, however, the dissolved body is more volatile than water then the boiling point is lowered. Fatty bodies combined with water raise the boiling point. Hence it is that boiling soup is hotter than boiling water. An increase of pressure raises and a diminution of pressure lowers the boiling point. When the pressure is great, the vapour, in order to escape, must have a higher tension, and thus requires a higher temperature. When the pressure is small, the reverse is the case. This is easily illustrated with an air-pump. Under the bell glass of the air-pump place a small saucer nearly filled with water. The water enters into ebullition even at ordinary temperatures when the air is exhausted. This is because of the diminished pressure. If it be desirable to continue the experiment for some time, the vapour must be removed by placing the

saucer in a vessel containing strong sulphuric acid. There is no increase of temperature in the water, but on the contrary, it falls; and by this experiment the water may be actually frozen. On the summit of Mont Blanc water boils at 180·95° F. The lowering of the temperature is about 1° F. for every 590 feet that we ascend. When the interior of a vessel is rough, the projecting points form centres for the developing vapour, and the boiling point is lower than when the interior surface is quite smooth.

Winds.—Wind is air put in motion. The air is never entirely free from motion, but its velocity is perpetually changing. The principal cause of these movements of the atmosphere is the variation of temperature produced by the alternation of day and night, and the succession of the seasons. When, through the heat of the sun, a portion of the earth's surface is heated to a greater degree than the remainder, the air resting upon it becomes rarefied and ascends, while a current of colder air rushes in to supply the vacancy. Thus two distinct currents will be produced —the one warm, moving out, and the other cold, moving in. To these movements of the atmosphere we apply the term wind.

If the whole surface of the globe were covered with water the winds would always follow the sun, and blow uniformly from east to west. The direction of the wind is subject to constant interruption from mountains, deserts, plains, oceans, and seas. Mountains covered with snow condense the air brought into contact with them, and when the temperature of a current of air is changed, its direction is likely to be changed. The ocean is never heated to the same degree as the land. The consequence is, that the general direction of the wind is from tracts of ocean

to tracts of land. In those parts of the globe which present an extended surface of water the wind blows with great regularity.

Winds are divided into three classes—regular winds, periodic winds, and variable winds.

Regular winds are those which blow throughout the year in the same direction. They occur in the neighbourhood of the equator, and extend about 30 degrees on each side. From their advantage to commerce they are called trade winds. On the north side of the equator they blow from the north-east, and on the south side they blow from the south-east. These winds arise from currents of air flowing from the polar regions towards the equator. The velocity of the earth about its axis being greater as we approach the equator, these winds lag behind, as it were, and become inclined to the westward, giving north-east winds on the north side and south-east winds on the south side.

Periodic winds are those which, at regular intervals of time, blow from opposite directions. Such are monsoons, that prevail in the Indian Ocean, blowing one half the year from north-east to south-west, and the other half in the opposite direction. When the sun is on the north of the equator the southern portion of the Asiatic continent is warmer than the southern part of Africa, and the winds blow from south-west to north-east. When the sun is on the south side the reverse is the case.

Variable winds are those which blow sometimes in one direction, sometimes in another. The farther we remove from the equatorial regions the more variable are the winds.

Clouds are masses of watery vapour evaporated from the earth, and partially condensed in the higher

regions of the atmosphere. When air saturated with vapour, in immediate contact with the surface of the earth, is cooled down rapidly, its vapour is condensed.

If the condensation is not sufficient to allow it to fall in the form of drops of rain, it floats above the surface of the earth as mist or fog. Clouds differ only in one respect from a fog: they float in the atmosphere at a greater elevation.

Rain is a fall of drops of water from the atmosphere. When several vesicles of vapour, through condensation in the clouds, unite, the weight becomes too great to be supported by the air, and the drop thus formed falls to the ground. Rain falls most abundantly in countries near the equator, and decreases as we approach the poles. The quantity of rain that falls in any country depends upon its neighbourhood to the ocean or large bodies of water, upon the season, upon the temperature, and the prevailing direction of the winds. More rain falls near the coast than in the interior of the country; more rain falls in summer than in winter; more rain falls in tropical than in temperate climates; and more rain falls in those countries where the prevailing winds are from the ocean. The average yearly fall of rain in the tropics is ninety-five inches; in the temperate zone it is only thirty-five. The depth of rain which falls yearly in London is about twenty-five inches, but at Vera Cruz, in the Gulf of Mexico, it is two hundred and seventy-eight inches. The explanation of this is to be found in the peculiar situation of the city, at the base of lofty mountains whose summits are covered with perpetual snow. Against these mountains the hot, humid air from the sea is driven by the winds, condensed, and its excess of moisture is precipitated as rain on the city of Vera Cruz. The mountain

chains of the west coasts of England and Ireland receive, with the west and south-west winds which generally prevail, the vapour of the Gulf Stream; in consequence, the annual fall of rain is much greater on the south-west side of the mountain chain than it is on the eastern and southern coasts, or the north-east side of that range of mountains which stretch along the coasts of England and Ireland.

The total amount of rain which fell at various stations in Ireland, in 1851, is given in inches as follows:—

Portarlington . .	21·2
Killough . . .	23·2
Dublin . . .	26·4
Castletownsend . .	42·5
Westport . . .	45·9
Cahirciveen . .	59·4

Thus Portarlington lies to the north-east of Slieve-bloom, Killough to the north-east of the Mourne range, Dublin north-east of the Wicklow range. On the other hand, the stations of greatest rain—Cahirciveen, Castletownsend, and Westport—are near to high mountain ranges, but on a different side.

RÉSUMÉ.

Specific heat is a term applied to the thermometric quantity of heat necessary to raise different bodies to the same temperature.

The quantity of heat which will raise olive oil two degrees will only raise water one degree. Hence a pound of water at 212 degrees may be said to contain twice as much heat, or twice the capacity for heat,

that belongs to olive oil. The specific heat of water $= 1$; oil $= 0{\cdot}5$.

Latent Heat.—When a solid passes into a liquid state the temperature remains the same. Bodies in changing their condition absorb a considerable amount of heat which is not indicated by the thermometer : this is called latent heat. The temperature of a liquid remains constant during ebullition, and a considerable quantity of heat is absorbed while the liquid passes into an aëriform condition. This heat is not indicated by the thermometer, for the vapour is of the same or even a lower temperature than the liquid. The heat absorbed is said to be latent.

Thermometers are instruments for determining the temperature of bodies. When the sensible heat increases or diminishes, the temperature is said to rise or fall. The mercurial thermometer is the one most extensively used.

The alcohol thermometer differs from the mercurial thermometer by being filled with coloured alcohol, and is chiefly used for low temperatures.

The differential thermometer is used for showing the difference of temperature between two places.

Ebullition, or boiling, is the rapid production of elastic bubbles of vapour in the mass of the liquid. The first bubbles are due to the disengagement of air previously absorbed. Bubbles of vapour then rise from the heated sides of the vessel, but as they pass through the upper part of the liquid, which is of a lower temperature, they condense before reaching the surface. The formation and condensation of these bubbles constitute the singing noise which is heard before the liquid begins to boil. Large bubbles now rise and burst on the surface, and this constitutes the phenomenon of ebullition. The boiling point is

influenced by the shape of the vessel and the pressure.

Winds are produced by a disturbance of the equilibrium in some part of the atmosphere. This disturbance results from the difference in temperature between adjacent countries.

Regular winds are those which blow all the year in the same direction. They are known as the trade winds. In the northern hemisphere they blow from the north-east to the south-west, and in the southern hemisphere they blow from south-east to the north-west.

Periodic winds are those which blow regularly in the same direction, at the same seasons, and at the same hours of the day. The simoom, monsoon, and the land and sea breezes are examples of this class of winds.

Variable winds are those which blow sometimes in one direction, sometimes in another, without apparently being subject to any law.

Clouds are masses of vapour condensed into drops of extreme minuteness. They only differ from fogs in occupying a higher region of the atmosphere. They always result from the condensation of vapours which rise from the earth.

Rain.—When the watery vapour is condensed, and the small particles, by uniting with others, become larger and heavier, they form regular drops, which fall as rain.

The Dynamical Theory of Heat (taken chiefly from Professor Tyndall's Lectures "*On Heat considered as a Mode of Motion*").—After stating the methods by which we determine the mechanical effect, by multiplying the mass of a body into its velocity, several experiments are described for the generation of heat by

mechanical processes. A leaden bullet is placed on an anvil, and struck with a sledge hammer. The amount of heat generated by percussion is sufficient to raise the temperature of the bullet; and if the heat generated could be collected without loss, "we should be able, by means of it, to raise the hammer to the height from which it fell." An elevation of temperature is also produced by compression and friction, and the mechanical force expended in producing heat may be expressed in equivalents of heat and work. The combustion of 1 lb. of coal produces a sufficient amount of heat, when applied mechanically, to raise a weight of 100 lbs., in opposition to gravity, a height of 20 miles; and conversely, 100 lbs. falling from a height of 20 miles would generate an amount of heat equal to that produced by the combustion of 1 lb. of coal. The heat of the sun is supposed to be kept up by meteorites falling with immense velocity on the sun. The envelope which surrounds the sun, and is known to astronomers as the zodiacal light, may be a crowd of meteors moving with immense velocity towards the sun, and from this source the annual loss is made good. In the same way combustion may be due to the clashing together of the particles of oxygen and the constituents of the lighted body. All cases of combustion are ascribed to this collision of particles urged together by the force of chemical attraction. Expansion of volume results from imparting heat to bodies until the force of cohesion is so far diminished as to permit the particles to move freely over each other. This is the liquid condition of matter. With every fresh increment of heat the force of cohesion is still further diminished, and at last we have the vaporous or gaseous form of matter. The distribution of heat by the transfer of heated

particles from place to place is called *convection*, but the transfer of heat which consists in each atom taking up the motion of its neighbours is called *conduction*.

Extracts from the Second Book of the "Novum Organum."—"When I say of motion that it is the genus of which heat is a species, I would be understood to mean not that heat generates motion or that motion generates heat (though both are true in certain cases), but that heat itself, its essence and quiddity, is motion and nothing else, limited, however, by the specific differences which I will presently subjoin, as soon as I have added a few cautions for the sake of avoiding ambiguity.

"Nor, again, must the communication of heat, or its transitive nature, by means of which a body becomes hot when a hot body is applied to it, be confounded with the form of heat; for heat is one thing and heating another. Heat is produced by the motion of attrition without any preceding heat.

"Heat is an expansive motion, whereby a body strives to dilate and stretch itself to a larger sphere or dimension than it had previously occupied. This difference is most observable in flame, where the smoke or thick vapour manifestly dilates and expands into flame.

"It is shown also in all boiling liquid, which manifestly swells, rises, and bubbles, and carries on the process of self-expansion till it turns into a body far more extended and dilated than the liquid itself, namely, into vapour, smoke, and air.

"The third specific difference is this:—Heat is a motion of expansion, not uniformly of the whole body together, but in the smaller parts of it; and at the same time checked, repelled, and beaten

back, so that the body acquires a motion alternate, perpetually quivering, striving, and struggling, and irritated by repercussion, whence springs the fury of fire and heat.

"When wind escapes from confinement, although it bursts forth with the greatest violence, there is no very great heat perceptible, because the motion is of the whole, without a motion alternating in the particles.

"In cold, contractive motion is checked by a resisting tendency to expand, just as in heat the expansive action is checked by a resisting tendency to contract. From this it follows that the form or true definition of heat (that is, heat in relation to the universe, not simply in relation to man), is, in a few words, as follows:—*Heat is a motion, expansive, restrained, and acting in its strife upon the smaller particles of bodies.*"

MAGNETISM.

Magnetism is that branch of physics which treats of the properties of magnets and their action on each other. A natural magnet, sometimes called a loadstone, is the magnetic oxide of iron, and it has the property of attracting other pieces of iron. These natural magnets are found in Sweden and Norway, and many places in the United States, especially in Arkansas. This property of attracting bodies was first noticed by the Greeks, in the town of Magnesia, in Lydia, and hence the term magnet.

If a natural magnet, no matter what its shape, be rolled in iron filings, and afterwards withdrawn, we shall find that the filings are accumulated most abundantly at two opposite points. These points are the poles of the magnet, and are the points of greatest attraction. When either of these points is held at a short distance from the iron filings they will be attracted to it, and adhere with considerable force. If we suspend by a silk thread a steel needle, and bring the pole of a loadstone near it, it will be attracted. If we place the needle on the surface of a tumbler of water, and bring any pole of the magnet outside the tumbler, the needle will be attracted towards the magnet, and the attractive force is in no degree diminished because of the interposition of the glass. While the loadstone thus attracts iron and all metallic bodies, these same bodies exercise a reciprocal attraction on the loadstone—action and reaction being opposite and equal.

The attractive power of the magnet, as we have just

seen, is not uniform over every part of its surface, but is principally exerted at opposite points or extremities of the surface. Between these two points a neutral point may be found, where the attractive influence disappears.

When a magnet is supported by a thread, or on a pivot, so as to move freely, it will rest only in one position, viz., with its poles or extremities directed nearly north and south. The extremity constantly pointing to the north is called the north pole, and the one that points to the south the south pole.

That property which will cause a magnet freely suspended to turn constantly the same extremity towards the same pole of the earth is termed the magnetic polarity or directive power.

When two bodies possessing magnetic properties are brought into contact, or near each other, the like poles will repel each other and the unlike attract each other.

If a piece of soft iron wire be suspended by a magnet through the attraction of one of its poles, the iron becomes magnetic, but only while it is in contact with the loadstone; but if, instead of iron, we use a piece of hardened steel and suspend it, the steel will have acquired a permanent magnetism, the strength of which will depend on the power of the magnet to which it was suspended and the length of time it remained in contact. A magnet thus made is said to be an artificial magnet; but other methods, more complex and efficacious, are employed, by which a very high degree of permanent magnetism is communicated to steel.

In order that a body should be made magnetic it is not absolutely necessary that it should be in contact with a magnetized body. The magnetism is com-

municated, though more feebly, when the two bodies are near each other, but not in contact.

Magnetic Induction.—If the north pole of a steel magnet, A (*Fig.* 37), be placed near the extremity of a

FIG. 37.

soft piece of iron, B, the end S of the soft iron will instantly acquire the properties of a south pole, and the opposite end, N, those of a north pole (the opposite poles would have been produced in the iron if the opposite end, S, of the magnet A had been placed near the iron B); and the iron, although only temporarily magnetic, will render another piece of iron, C, magnetic, and another piece, D; north and south poles being produced at N S and N S. The magnetism in B, C, and D is said to be induced.

Iron attracted by a magnet reacts on the magnet, and attracts in return, and the same takes place on a bar of iron in which magnetism is induced. It reacts on the magnet which induces the magnetism, and increases its magnetic intensity. From this we have a distinct explanation of the remarkable fact that a magnet has its power increased by having a bar of soft iron placed in contact with one of its poles; and if we gradually add fresh pieces of iron in small quantities, in addition to that which the magnet already carries, the power of the magnet increases with the reaction of each separate piece it is made to carry. If a bar of iron on which magnetism has been induced is long, and the strength of the magnet great, a succession of poles is produced along its entire length, a north pole always following a south pole, or a south pole always following a north pole.

Magnetic attraction and repulsion are the necessary consequences of magnetic induction. The magnet attracts a piece of iron by inducing an opposite polarity at the end in contact with it, and the two opposite principles attract each other. In like manner, the north pole of one magnet attracts the south pole of another, and similar poles repel each other, in consequence of the attraction and repulsion of the opposite or similar principles. The attraction of iron filings is explained in the same way. Every particle of iron next the magnet has magnetism induced upon it, and it becomes a minute magnet: this particle makes the next particle a magnet; and so, the opposite polarities being induced in each of the particles, they attract one another the same as if they were each real magnets. A bar of soft iron becomes magnetic by simple contact with a magnet, but this effect is only of a temporary character.

Magnetic Needles.—To magnetize a body is to impart to it the properties of a magnet. The only substances that can be permanently magnetized are steel and an oxide of iron, $FeO+Fe_2O_3$, which is the formula of the natural loadstone. A body capable of being magnetized may be converted into a magnet by the slow inductive influence of the earth, but more readily by being rubbed by another magnet, or placed within the influence of two magnets, or by the action of electricity.

Bars of steel and compass needles are usually magnetized by rubbing them with other magnets. The three methods are called magnetism by *single touch*, by *separate touch*, by *double touch*.

To magnetize a steel bar by *single touch*, we hold the steel bar or body to be magnetized with one hand. We move along its surface, in one direction, a powerful

bar magnet. After several repetitions of this process (well raising into the air the bar magnet at the end), the steel bar will have acquired all the properties of a magnet.

To magnetize a steel bar by *separate touch* we rub the bar from its centre, in one direction, with one pole of a magnetized bar, and in the opposite direction with the opposite pole.

To magnetize a bar by *double touch* two magnetized bars are employed, which are placed with their opposite poles in contact with the bar at its middle point, being only separated by a small interval by a piece of cork or ivory. The bars are then simultaneously moved first towards one end, and then from this to the other end, and this operation is repeated several times, taking care to finish in the middle. The bars must be kept inclined at an angle of about 30° or 40°, and the same number of strokes must be applied to each half of the bar.

A bundle of magnets consists of a group of magnetized bars united so that the same poles are coincident. Sometimes these bundles are composed of straight bars, and sometimes curved in the shape of a horseshoe. Magnets, if left to themselves, lose in time much of their power. Hence it is that armatures are used.

An armature is a piece of soft iron placed in contact with the poles of a magnet. The poles acting by induction convert one end of the iron into a south pole and the other into a north pole. These two poles acting on the opposite poles of the magnet preserve the magnetism of the magnet.

If weights be attached to the armature of a magnet till it separates we can judge of the power of the magnet.

For most experiments the horseshoe magnet is to be preferred. It is also best adapted for the armature or keeper.

To account for the various phenomena of magnetism the hypothesis of two fluids has been proposed, which supposes that the particles of all bodies susceptible of magnetism are pervaded with these fluids. In a particle of soft iron these fluids are supposed to be neutral or inert, and that when they are decomposed the particles of one fluid, called the austral or southern magnetism, attract those of the boreal or northern fluid, and *vice versâ*, while they each repel one another.

The force required to separate the two fluids in a magnetic body is called the Coercive Force. The fluids are not separated with equal facility in all bodies. In some, as for example in soft iron, they yield easily and separate at once; in others, as hardened steel, the fluids yield with difficulty, and a powerful magnet is required to effect the separation. The harder and better tempered the steel the more difficult it is to separate the two fluids. Soft iron, as we before mentioned, in contact with a magnetized bar becomes a magnet at once, and on being removed returns to its neutral condition. With hardened steel it takes considerable force and some time to render it a magnet, and on being removed from the source by which it became a magnet it continues a magnet.

Directive Force of Magnets.—A permanently magnetized needle, balanced on its neutral point so that it can turn freely in a horizontal direction, assumes, after a few oscillations, a determinate direction nearly north and south. If, instead of placing the needle on a pivot, it be attached to a piece of cork and placed in a vessel of water so that the needle may

float in a horizontal position, it will, in a short time, come to a state of rest, pointing in the same direction as if it were balanced on a pivot. In this experiment it will be found that the needle, once in meridian, does not move either towards the north or the south. Hence we infer that the force exerted on the needle is simply a directive force, and the force which causes a moveable magnet to place itself north and south is called its directive force. Since the phenomenon described takes place at all points on the earth's surface, the globe has been regarded as an immense magnet, having its boreal and austral poles near the north and south poles of the earth, and its neutral line near the equator. An immense magnet acting on smaller magnets would produce all the effects observed.

The Mariner's Compass (*Fig.* 38) consists of a magnetized needle turning horizontally on a pivot, and

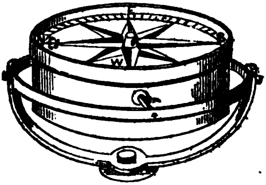


FIG. 38.

enclosed within a shallow circular box. At the bottom of the box is a card, with the chief cardinal points of the horizon, N., S., E., W., marked upon it. These four divisions are each divided into eight parts, which are called the points of the compass, or rhumbs. An enumeration of these points from memory is called "boxing the compass." The needle is attached to the under side of the card, and is out of sight. The box

is supported by means of two concentric hoops, called gimbals, so arranged that whichever way the ship may roll the card preserves its horizontal position. In a land compass the card is fixed at the bottom of the box, and the needle moves over its surface. It is commonly used by travellers and surveyors for determining the different points of the horizon. The box is turned so as to bring the N. and S. points of the card under the N. and S. points of the needle. All other points are now correctly placed with reference to the magnetic meridian.

If an ordinary needle be suspended from its centre of gravity, it will hang horizontally, and show no disposition or inclination to depart from the horizontal line; but if we make the needle a magnet, then it will no longer be in the horizontal plane, but one pole will incline downward, and of course the other upward. Such an arrangement is called a dipping needle. The inclination in the latitude of London is 70°.

Magnetic Meridian.—Although we have spoken of magnets pointing north and south, accurate observations have shown that this is not exactly the case. If we imagine a plane passed through the needle when in this position, and the centre of the earth, we shall have the plane of the magnetic meridian. This plane does not coincide with the true meridian, which is a great circle drawn around the earth, passing through both poles and any given point on its surface, and intersecting the equator at right angles. The angle formed by the magnetic meridian and the terrestrial meridian at any place is called the variation or declination of the needle.

The declination of the needle is its variation from due north and south. This is different at different places, and even at the same place at different

times. When the north pole of the needle points to the east of true north the declination is said to be east; when to the west of true north it is said to be to the west. There is a line running from 60° to the west of Hudson's Bay, then in a southerly direction through the American lakes to the West Indies, through Cleveland, to near Charleston, along which the needle points to true north. This is called the line of no declination. There is also a line of no variation, which begins in the White Sea, and makes a great sweep in a semicircular direction eastward until it reaches to latitude 71°; it then passes along the Sea of Japan, goes westward across China and Hindostan to Bombay; it then bends east, touches Australia, and goes south. In proceeding in either direction, east or west, from these lines of no variation, the declination of the needle gradually increases, and becomes a maximum at a certain intermediate point between these lines. The line of no declination is moving gradually westward. Besides this slow change, the magnetic needle undergoes others, some of which are regular and some irregular. In our latitude the north end of the needle is moving slowly towards the west during the early part of the day, and back again during the latter part of the day. This is called the diurnal variation. In the southern hemisphere the motion is reversed. There is also a small change of a similar nature which takes place annually, called the annual variation. Irregular changes are called perturbations. They take place during a thunder storm, aurora borealis, and any sudden change in the electrical condition of the atmosphere.

The two magnetic poles of the earth are situated within the vicinity of the poles of the earth's axis, and are called the magnetic north pole and the magnetic south pole. These contrary poles attract

each other, and thus a magnetic needle will turn its south pole to the north and its north pole to the south. What we call the north pole of the needle is in fact its south pole.

The exact position of the northern magnetic pole is about 19° from the north pole of the earth, in the direction of Hudson's Bay. It was visited by Sir J. Franklin and Sir J. Ross in 1832. The south magnetic pole is in the antarctic continent, and has been approached within 170 miles. If an ordinary compass be carried to either of these poles it will lose its power, and point indifferently in any direction. If it be carried beyond the magnetic pole to any point between the true pole of the earth and the magnetic pole, the poles of the needle become reversed, the end called the north pointing to the south and the end called the south pointing to the north.

The position assumed by the needle varies in different latitudes. If it were carried directly to the north magnetic pole its south pole would be attracted downward, and would stand vertically; at the south magnetic pole its position would be exactly reversed. The earth's magnetism varies very much in different parts. At the magnetic equator it is most feeble, and gradually increases towards the poles. The intensity of terrestrial magnetism in different places is measured by the number of vibrations made in a given time by a magnetic needle.

If a dipping magnetic needle be taken to a point midway between the north and south magnetic poles, it will of course be attracted equally, and will assume a horizontal position, or cease to dip; but as we proceed either north or south it dips more and more, until, at the magnetic poles, as before mentioned, it becomes perpendicular.

As the directive tendency of the magnetic needle arises from its poles being attracted by those of the earth, it is clear, from the rotundity of the earth, that its poles will not be attracted by those of the earth horizontally but downwards, so that the needle cannot tend to be horizontal, except when both its poles are acted upon equally, and that is when it is midway between them. Accordingly, a needle which balanced, as we have before mentioned, before it was magnetized, will no longer balance itself when magnetized. This dip is corrected in ships' compasses by a small sliding weight, which has to be removed as the ship moves towards the equator, and placed on the opposite side of the needle when in another hemisphere.

A body may be magnetized by *terrestrial induction*. A body capable of being magnetized may be converted into a magnet by the inductive influence of the earth, or more rapidly by being rubbed with a natural magnet. Natural magnets owe their magnetism to the slow induction of the earth. If we place a thin bar of iron in the magnetic meridian, and incline it to the horizon according to the angle of its dip, the earth acts upon it by induction. The magnetism thus induced is only temporary, for if the bar be removed from its position the effect disappears. If, however, when the bar is in this position it be struck smartly with a hammer, or if it be violently twisted, sufficient coercive force may be developed to make the induced magnetism permanent. The properties of a magnet are not at all affected by the presence or absence of air. The power of a magnet is greatly weakened by heating it, and a white heat entirely destroys it.

RÉSUMÉ.

Magnets are characterized by their power of attracting iron, nickel, cobalt, and chromium.

Natural magnets are the magnetic oxide of iron, $FeO + Fe_2O_3$.

Artificial magnets.

The attraction of a magnet for iron is reciprocal.

The magnetic force may be communicated through the entire mass of such bodies as are capable of receiving it.

The magnetic force decreases with the distance. It is also diminished with an increase of temperature, and a white heat entirely destroys it.

All magnets have two poles—the austral or south pole, the boreal or north pole—and a point neutral.

Similar poles repel and opposite poles attract.

The magnetic force diminishes in the same ratio as that of all forces acting from a centre, viz., as the squares of the distances. If the distance be increased 2, 3, 4, n times, the attractive force will be $\frac{1}{4}$, $\frac{1}{9}$, $\frac{1}{16}$, $\frac{1}{n^2}$ of what it is at the distance taken as a unit.

Magnetism of a temporary character is imparted to a bar of soft iron by contact with a magnet. In a steel bar the magnetism is of a more permanent character.

Bars may be magnetized by single touch, by separate touch, by double touch.

A bundle of magnetized bars. Armature.

A magnetic needle free to move on a pivot assumes a certain determinate direction slightly different to the geographical meridian.

The austral or south pole points towards the north, and the boreal or north pole points towards the south.

The magnetic action of the earth on the needle is simply directive. It acts as a magnet.

The magnetic meridian is the direction assumed by a horizontal needle in any given place.

The declination of a magnetic needle is the angle formed by the magnetic meridian and the geographical meridian. It may be either east or west.

The diurnal and annual variations in the declination of the needle differ according to the time of day or year, and the place.

There are two lines on the surface of the earth where the magnetic meridian coincides with the geographical meridian, and these are called lines of no declination, or azonic lines. The declination of the needle is also affected by disturbances in the earth's magnetic power, such as earthquakes, volcanoes, storms, and the aurora borealis.

ELECTRICITY.

Electricity is that branch of physics which treats of the laws of attraction and repulsion exhibited by bodies under certain circumstances.

Electricity is one of those subtle agents without weight or form which appears diffused through all nature, existing in all substances, without affecting either their volume or temperature, or giving any indication of its presence when in a latent condition. When, however, it is liberated from this condition, it is capable of producing the most sudden and destructive effects, or of exciting powerful influences by long-continued action. Electricity may be excited or called into action by mechanical, physical, or chemical action.

The mechanical sources of electricity are friction, pressure, and a separation of the molecules or particles of a body. If a piece of loaf sugar be suddenly broken in a dark room, a feeble light is emitted, which is due to the development of electricity at the moment of separation of the particles.

The physical sources of electricity are variations of temperature. Some minerals, on being heated or cooled, exhibit electrical phenomena.

The chemical sources of electricity are the composition and decomposition of chemical compounds. Metals, such as zinc, copper, iron, and the like, when thrown into a solution of sulphuric acid and water, are attacked, and form compounds known as salts. During these changes considerable quantities of electricity are developed. The most prominent and

important causes of electricity are friction and chemical action.

Discovery of Electrical Properties.—More than two thousand years ago Thales knew that when amber was rubbed with wool it acquired the property of attracting light bodies, such as small pieces of paper, the barbs of a feather, and the like. The ancients explained this phenomenon by supposing that amber had the power of suction, and that light bodies were sucked towards it. As amber was a rather rare substance, and its origin not well understood, they said it was formed from the tears of a large Indian bird. Six centuries after the death of Thales, Pliny says that the friction of the fingers imparts life to yellow amber, which attracts straws, the same as the loadstone attracts iron. This was all the knowledge possessed of this subject until the end of the sixteenth century, when Gilbert called attention to the properties of amber, and showed that not only amber but a great number of other substances, such as glass, resin, sulphur, and the like, acquired the same property as the amber by being rubbed with a woollen cloth or a catskin. This experiment is easily performed. Rub a stick of sealing wax or glass with a woollen cloth; then present it to light shreds of gold leaf, or fragments of paper, and they will be seen to approach and adhere to the glass or sealing wax with which the experiment was made. It may be also observed that these rubbed bodies become luminous, and emit sparks and display a number of other properties known as electrical phenomena. During the last century a number of new facts have been discovered, which now form a rather extensive range of science.

We have just mentioned that a rod of smooth glass or a stick of sealing wax, rubbed with a piece of

woollen cloth or dry flannel, will be found to have acquired a new physical property, viz., that of instantly attracting small bodies. Some of these will adhere to the rod or stick; others will fall back on the table; and others be thrown off as if they were repelled. The property which has been communicated by friction is called electricity; the body which acquires this property is called an electric; and the attraction of the bodies is called electrical attraction. The electric, or body rubbed, is said to be excited or electrified, and the body by which it is rubbed is called the rubber.

These simple phenomena may be shown by the action of resinous bodies on a dry pith ball, or piece of cork about the size of a small pea. Let the ball (*Fig.* 39) be suspended by a fibre of raw silk. Having rubbed a glass rod with a piece of dry silk, present it to the ball B, and the ball will instantly be attracted to the rod and adhere to it. After they have been in contact for a second or two, withdraw the glass rod without touching the ball with the fingers. If the excited glass rod be again excited, and presented a second time to the ball, it will recede from it, or be repelled. If, after touching the ball with the finger, so as to deprive it of its electricity, the experiment be repeated with a stick of sealing wax instead of glass, the very same phenomena will occur: the ball will be first attracted and then repelled. From these experiments we ob-

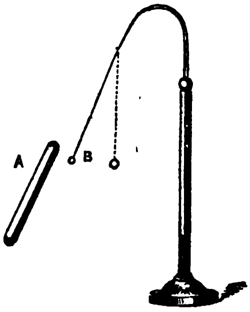


FIG. 39.

serve that both the glass and sealing wax attract the ball B before they have communicated to it any of their electricity, and that both these electrics repel the ball after each of them has communicated a portion of its electricity to the ball. Let us now see what takes place when the excited sealing wax is presented to the ball after the ball has received electricity from the glass rod, and *vice versâ*. Excite the glass rod and present it to the ball, and after it has been a second or two in contact, remove it. The ball has now received electricity from the glass rod. Excite the sealing wax and present it to the ball. The ball will not be repelled, but attracted. Reverse the experiment, by first presenting the excited wax to the ball, and then the glass, and it will be found that the glass repels the ball.

Excited glass repels a ball electrified by excited glass. Excited wax repels a ball electrified by excited wax. Excited glass attracts a ball electrified by excited wax. Excited wax attracts a ball electrified by excited glass. From this it appears that there are two opposite kinds of electricity, viz., that produced by excited glass, and that produced by excited wax. To the electricity excited by the glass the name positive is given; to that excited by the wax the name negative is given.

After the pith ball has been electrified, either with an excited glass rod or sealing wax, we touch it with a rod of glass. The property of its being subsequently attracted or repelled by an excited rod of glass or wax will not be altered; but if we touch it with a rod of metal, it will lose the electricity which it received from the glass rod or wax, and return to the condition it was in when they were first applied to it. The glass rod and the rod of metal possess different properties. The metal carries off the electricity

from the ball, and is a conductor, and the glass a non-conductor.

The hypothesis of two electrical fluids, which, in unexcited bodies, exist in a state of combination, forms what is called a neutral fluid. The earth is regarded as the great reservoir of this fluid, which has of itself no obvious active properties. Hence bodies which simply contain it are said to be neutral. If, by friction or chemical action, or other causes, the neutral fluid is decomposed, and the two fluids separate, electrical phenomena are at once developed. The positive fluid is frequently indicated by the sign +, and the negative by the sign —. All the phenomena can be easily explained by the theory of a single fluid, and if mention is made of two fluids it is simply because the hypothesis is more easily applied and generally used.

Fluids of the same name repel each other. Fluids of opposite names attract each other. If the quantities of dissimilar fluids be exactly equal they neutralize each other; that is, they bring about a state of electrical indifference.

Conductors, or conducting bodies, are those which permit the electricity to pass along them. The best conductors are the metals. After these come plumbago, well-calcined charcoal, carbonic acid, and saline solutions; water, either in a liquid or vaporous form; the human body, or animal tissues; vegetable substances, and in general all moist or humid bodies.

Insulators, or nonconducting bodies, are those which do not permit electricity to pass readily along them. The best nonconductors are resins, gums, india rubber, silk, glass, precious stones, spirits of turpentine, oils, air, and gases when perfectly dry.

Methods of Electrifying Bodies.—Noncon-

ducting bodies are only electrified by friction, but conductors may be electrified either by friction, by contact, or by induction. To electrify a metal it must be insulated—that is, it must be supported by a non-conducting body—and it must be rubbed by an insulated body. This may be accomplished by mounting the metal on a stand of glass and rubbing it with a nonconductor (a piece of dry silk). Were the metal not insulated, the electricity would flow off to the earth as fast as generated ; and if the rubbing body were not a nonconductor, the electricity would flow off through the arms and legs of the experimenter.

The method of electrifying a body by conduct depends upon the property of conductibility. If a conductor is brought into contact with an electrified body, a portion of the electricity of the latter flows upon the former body. If the two electricities are alike, the electricity will be equally distributed over both. If they differ in size or shape, the electricity will not be equally distributed over both. The method of electrifying bodies by induction is similar to that of magnetizing bodies by induction.

We have just mentioned that when one body, charged with one kind of electricity, is brought into close proximity with other bodies, it induces, without actual contact, an opposite electrical condition, called—

Electrical Induction.—This effect arises from the general law of electrical attraction and repulsion. A body in its neutral condition is supposed to contain equal quantities of negative and positive electricity, and when this is the case the body is in a state of equilibrium ; but when a body charged with electricity is brought into proximity with a neutral body, disturbance immediately takes place. The electrified body, by its attractive and repulsive influence, separates

the two electricities of the neutral body; repelling the one like itself, and attracting the opposite. Thus a body positively electrified brought near a neutral body, the positive electricity of the neutral body will be repelled or driven to the most remote part of its surface, but the negative electricity will be attracted to the point nearest to the disturbing body. Between these extreme points we can imagine a point which is neutral, separating, as it were, the two opposite fluids.

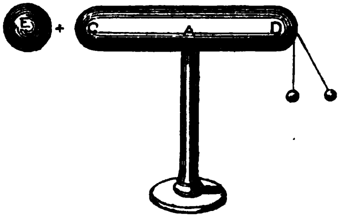


FIG. 40.

Let C A D (*Fig.* 40) be a metallic cylinder placed on an insulating support, with two pith balls suspended at the end D. If now an electrified body, such as an electrophorus, be brought near to the end C of the cylinder, the balls at the other extremity will instantly diverge, showing the presence of free electricity. This does not arise from any transfer of the electricity from the electrified body E to C, for upon withdrawing the electrified body E the balls will fall together and appear unelectrified as before; but the electricity in E decomposes, by its proximity, the two electricities in the cylinder; attracting the kind opposite to itself to the one end, and repelling the same kind to the other end. The middle point, A, will be neutral, and will neither exhibit positive nor negative electricity. If

three cylinders (*Fig.* 41) are placed in a row touching one another, and a positively electrified body, E, be brought into proximity to one extremity, the electricities of the cylinders will be decomposed, the

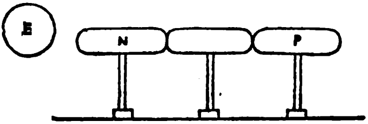


FIG. 41.

negative accumulating in N and the positive repelled to P. If, in this condition, the cylinder P be first removed, then the electrified body, the separate electricities will not be able to unite, as in the former illustration, but N will remain negatively and P positively electrified. From these experiments we can understand why an electrified surface attracts a neutral or unelectrified body, such as a pith ball. It is not that the electricity causes attractions between excited and unexcited bodies, the same as between bodies in opposite electrical states, but the pith ball is first rendered opposite by induction and is then attracted in consequence of this opposition. A pith ball a few inches from the surface of an electrified body is charged with electricity by induction, and the kind being contrary to that of the surface, attraction takes place. When the two touch they become of the same kind by conduction.

Theory of Induction.—Faraday conceives electrical induction to depend on a physical action between the contiguous molecules, which never takes place at a distance without operating through the intervening particles of nonconducting matter. In

these intermediate particles a separation of the opposite electricities takes place, and they become decomposed in an alternate series or succession of positive or negative points or poles. This he terms a polarization of the particles; and in this way the force is transmitted to a distance. Thus, in *Fig.* 42, P represents a body positively charged with electricity, and the particles between are air or other nonconducting matter. Then the action of P is transmitted to a distant body, N, by the separation and electrical polarization of the particles indicated by the black and white hemispheres. If the particles can retain this state, insulation is the result; but if the forces communicate, or discharge one into the other, then we have an equalization of the respective opposite electricities throughout the whole series, including P and N. He further assumes that all particles of matter are more or less conductors; that in their quiescent state they are not arranged in a polarized form, but become so by the influence of contiguous and charged particles: they then assume a forced state, and tend to return by a more powerful tension to their original normal condition; that being more or less conductors the particles charge either bodily or by polarity; that contiguous particles can communicate their forces more or less readily one to the other,—when less readily the polarized state rises higher, and insulation is the result; when more readily conduction is the result. Insulation of an ordinary kind is the action of a charged body upon insulating matter, or matter the particles of which communicate the electrical forces to each other in an extremely minute degree, the charged body

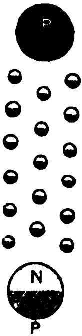


FIG. 42.

producing in it an equal amount of the opposite force, and this it does by polarizing the particles.

An Electroscope is an instrument employed to indicate free electricity. The most simple form of electroscope is the electrical pendulum (*Fig.* 39, p. 107), which consists of a light pith ball suspended by a fine silk thread. The thread is fastened to the upper end of a stem of copper, which stem has a support of glass. To ascertain if a body, A, is electrified, it is presented to the pith ball. If it be electrified, the pith ball, B, will be attracted; if not, it will remain in its vertical position.

There is another form of pith ball *electroscope* (*Fig.* 43), which consists of two balls suspended by conducting threads in a glass jar, and connected with a brass cap. On touching the brass cap, B, with the electrified body, C, the two balls, being similarly electrified, will repel each other. A more delicate *electroscope* consists of two slips of gold leaf instead of the pith balls. If an excited substance, C, be brought near the brass cap, B, the two leaves will instantly diverge. When no electricity is present the two gold leaves hang together.

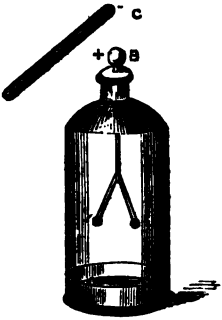


FIG. 43.

ELECTROMETERS must be insulated and dry, so that the electricity communicated to the balls or leaves may not pass away. Another form, called the QUADRANT ELECTROMETER (*Fig.* 44), consists of a semicircle of white varnished paper, B, or ivory, fixed on a vertical rod, which may be attached to the conductor of an

electrical machine. From the centre of the semicircle a light pith ball is suspended, and the number of degrees through which the ball A is attracted or repelled by any body brought into proximity with it indicates in a degree the amount of electricity present. No very accurate results can be obtained from this apparatus; and for more careful investigations Coulomb's is usually employed, called THE TORSION BALANCE (*Fig.* 45). A needle or stick of shellac, having at one end a small gilded pith ball, *o*, is suspended by a fibre of silk in a glass tube, which terminates in a cylindrical glass vessel about nine inches in diameter. The needle is so balanced that it is free to move horizontally in any direction about the point of suspension. When the pith ball is electrified by induction the repellant force causes the needle to turn round, and this produces a degree of torsion, or twist, in the silk which suspends it, and the tendency to untwist on return to its original position measures the force which turns the needle. Within

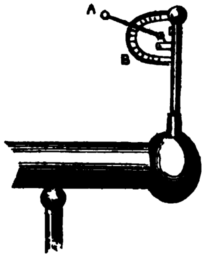


FIG. 44.

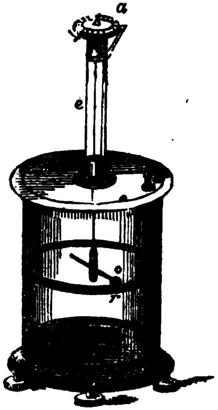


FIG. 45.

the glass vessel a graduated circle, *r*, is placed, which measures the angle through which the needle is deflected. In the cover of the vessel, at *d*, an aperture is made through which the electrified body is introduced. The ball *o* is insulated and supported by the glass cover, and the centre of this ball corresponds to the zero of the scale. In every experiment the charge must be communicated to the ball *o*, which is done by removing it from the apparatus and bringing it in contact with an electrified body, and then placing it in its proper position. The instrument is adjusted by levelling screws, and at the upper end of the tube *e* a circular piece of ivory, *a*, is placed, on which a scale is marked. A small index is attached to the fibre of silk, which moves round the centre of suspension and also indicates the degrees. By means of this balance Coulomb proved that the law of electrical attraction and repulsion was the same as that of gravitation, viz., the force varies inversely as the square of the distance.

The Electrophorus (*Fig.* 46) is a most valuable instrument, which is due to the ingenuity of Volta. By this machine we may obtain considerable quantities of electricity by induction. It consists of a circular cake of resin or shellac, A, laid upon a metallic plate, or a circular piece of wood covered with tinfoil. On this cake is placed a metallic cover, C, somewhat less in diameter than the cake, and furnished with a glass insulating handle, B. When the cake of resin has been negatively electrified by beating or rubbing vigorously with a cat-skin or dry silk, place upon it the metallic cover. The nega-

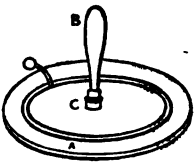


FIG. 46.

tive electricity of the resin, acting by induction on the neutral condition or the two electricities combined in the cover, separates them—the one, positive, is attracted to the under surface, and the negative repelled to the upper. On touching the cover with the finger all the negative electricity will escape, and the positive alone remains, which is combined with the negative electricity of the resin so long as the cover remains in contact. If we now remove the cover by its insulated handle, the positive electricity, which was at the lower part of the cover when in contact with the resin, will become free, and may be imparted to any insulated conductor adapted to receive it. The process may be repeated indefinitely, as the resinous cake loses none of its electricity, but simply acts by induction, and thus the insulated cover may be charged. This resinous or negative electricity which has been developed on the surface remains, on account of its insulating property, and the little tendency it has to attract moisture from the atmosphere. We must only take care to let the metal disc remain on the resin, the presence of which prevents the loss of electricity that would result from contact with the atmosphere. It is the negative electricity of the resin which, by decomposing the natural electricity of the metal plate, drives the negative electricity into the ground by means of the finger, and attracts the positive, which is found in the disc as soon as it is raised. If we raise it without having previously touched it with the finger, we find it charged not with positive electricity but a certain quantity of negative electricity, which it has taken from the cake by communication. This quantity is, however, always feeble.

RÉSUMÉ.

Discovery of Electrical Properties.—Thales, six centuries before the birth of Christ, discovered that amber rubbed with silk acquired the property of attracting light bodies. Gilbert, in the sixteenth century, found this property to exist in many other bodies.

Theories of Electricity.—Franklin assumed the existence of a peculiar subtle fluid which acts by repulsion on its own particles and pervades all bodies. By friction bodies acquire an additional quantity of this fluid, and are *positively* electrified. Others by friction lose a portion, and are *negatively* electrified. The former state corresponds to *vitreous* electricity, the latter to *resinous* electricity.

Symes assumes that every body contains an indefinite quantity of electrical fluid. This fluid is formed by the union of the positive and negative fluids. When in combination they neutralize each other. By friction and other means the fluids may be decomposed or separated.

Fluids of the same name repel each other. Fluids of opposite kinds attract each other.

Bodies have been divided into conductors and non-conductors. The best arrangement is a series in the order of decreasing conductibility.

The metals are good conductors.

Bad or non-conductors, such as glass, wax, sulphur, and resin, are called insulators.

Electricity may be developed by friction, pressure, cleavage, and chemical action.

Induction.—An insulated body, charged with either kind of electricity, acts on near bodies in a natural state like a magnet on soft iron; that is, it decomposes the neutral fluid, attracting the opposite and repelling

the like kind of electricity. This action is said to take place by induction.

An electroscope is an instrument for detecting the kind of electricity in any body.

The electrophorus is an inexpensive piece of apparatus, by means of which we may obtain considerable quantities of electricity. Its operation depends on the action of induction, of which it forms a good illustration.

An electrical machine is an apparatus by which electricity is developed and accumulated in a convenient manner for purposes of experiment. All electrical machines consist of three principal parts

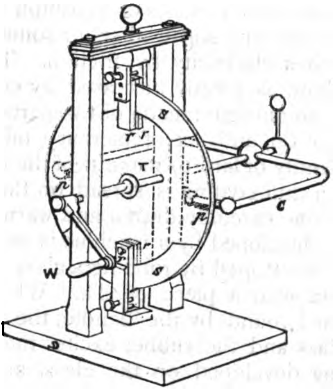


FIG. 47.

—the rubber; the body on whose surface the electric fluid is evolved; and one or more insulated conductors, upon which the electricity is confined.

There are two kinds of machines—the plate machine and cylinder machine. They derive their names from the shape of the glass employed. The plate machine (*Fig.* 47) consists of a large circular plate of glass, T, mounted on a brass axis, and supported by pillars fixed securely into the base, so that the plate can be turned by the handle W. At the top and bottom of the glass, and fixed so as to press easily but uniformly on the plate, are rubbbers, *r r r r*, and flaps of oiled silk, *s s*. When the machine is put in motion, these flaps of silk are drawn tightly against the glass, and thus the friction is increased and the electricity excited. The points *p p* collect the electricity from the glass as it revolves, and convey it to the prime conductor, C, which is insulated by standing on glass rods. The rubber of an electrical machine consists of a cushion stuffed with hair, and covered with soft leather, or some substance which generates electricity by friction. The efficacy of the machine is greatly increased by covering the cushion with an amalgam made of two parts, by weight, of zinc, one of tin, and six of mercury, mixed with a sufficient quantity of lard to make it of the consistency of a paste; a thin coating is spread on the cushions, and the machine carefully dusted and warmed.

Electricity developed by a machine is essentially the same as that developed by rubbing a glass rod or stick of sealing wax with a piece of silk. When the glass plate is turned round by the handle, the friction between the glass and the rubber excites the electricity, positive being developed on the glass, and negative upon the rubber. The points of the prime conductor are presented to the revolving glass plate, and the positive electricity is immediately transferred to it, and emits sparks to any conducting substance brought near it. The electricity thus abundantly developed is sup-

plied from the earth by means of a brass chain extending to the floor. That the electricity is derived from this source is evident from the fact that but a small quantity of electricity can be excited when the metallic connection between the rubber and ground is removed. The chain must always be attached to the rubber when it is desired to develop positive electricity, and to the prime conductor when it is desired to develop negative electricity. According to the single fluid theory the development of electricity is as follows:—The friction of the glass and silk, by disturbing the electrical equilibrium, deprives the rubber of its natural quantity of electricity, and it is therefore left in a negative state, unless a fresh supply be drawn from the earth to supply its place. The surplus quantity is collected on the prime conductor, which thereby becomes charged with positive electricity. On the theory of two fluids the same frictional action causes the separation of the vitreous from the resinous electricity in the rubber, which therefore remains resinously charged, unless there be a connection with the earth to restore the proportion of vitreous electricity of which the rubber has been deprived.

Other arrangements have been devised for the production and accumulation of electricity. High pressure steam escaping from a steam boiler carries with it minute particles of water, and the friction of these against the surface of the jet from which the steam issues produces electricity in great abundance. A machine of this sort at the Polytechnic produced flashes of electricity from the prime conductor more than twenty feet in length.

The Leyden jar (*Fig.* 48), as usually constituted, consists of a glass jar, having a wide mouth, and coated externally and internally, to within three inches

of the top, with tinfoil. A wooden cover of well-dried mahogany, varnished, is fitted into the mouth of the jar, through which a stout brass wire passes, having a

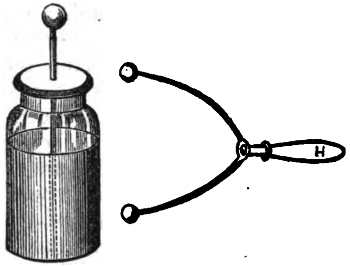


FIG. 48.

few inches of chain at the lower end, so as to be in contact with the inside coating. The top of the brass wire is terminated in a knob about three inches from the cover. The Leyden jar is charged by holding the outer tinned part in the hand and bringing the knob in contact with the prime conductor of the electrical machine. The positive fluid accumulates in the interior, and acts by induction on the outer coating, which becomes negative; the positive fluid in the outer coating being carried away by the hand through the body. After the jar has been charged, if it be held in one hand whilst the other is brought into contact with the knob, a shock is felt through the body, and the jar returns to its neutral state. When the jar has to be discharged without a shock, a discharger is used, which consists of two brass knobs, insulated by a glass handle, H. One knob is brought into contact with the outer coating of the jar, and the other is then brought into contact with the metallic knob of the jar.

In this case a spark is emitted, and the jar returns to its neutral condition.

An electrical battery is a number of Leyden jars so connected as to act like a single jar. The jars are placed in a box, the bottom of which is well covered with tinfoil. This serves to connect the outer surfaces of the jars. Their inside surfaces are brought into contact with brass rods connecting the several knobs of the jars. On one of the knobs is placed an electrometer, which indicates the excess of the fluid on the inner over the outer surfaces. The battery is charged in the same way as a Leyden jar. In discharging the battery a discharger with two glass handles should be employed, and care should be taken to touch the external covering before touching the brass knob.

An electrical condenser is an apparatus employed for accumulating electricity. The condenser of Epinus (*Fig.* 49) is composed of two metallic plates, C and B, standing on supports of glass, with an intervening plate of glass, A, somewhat larger than the metallic plates. These plates are so mounted on a stand as to be made to approach or recede from the plate A by sliding along a groove. When the condenser is used, the plates C and B are moved up to touch the plate A. The plate B communicates with the prime conductor of an electrical machine, and the plate C with the earth. The electrical machine is put in motion, which charges the plate B with positive electricity. Were it not for the plate C, the quantity of electricity on each unit

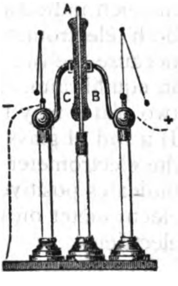


FIG. 49.

of surface of B would be the same as on a unit of surface of the prime conductor, but the presence of the plate C modifies the result. The plate B acts by induction on C, and drives its positive electricity to the earth, retaining its negative electricity by the force of attraction. The negative electricity of C now reacts on B, partially neutralizing the effect of its positive electricity. The electricity of B, being partially neutralized, no longer holds that of the prime conductor in equilibrium, and an additional quantity of the positive fluid flows into it, which, acting as before, draws into C from the earth an additional quantity of the negative fluid, and so on. In this way there is gradually accumulated upon the surfaces of B and C large quantities of the positive and negative fluids. When the apparatus is fully charged we disconnect C with the earth and B with the prime conductor. In this condition the two electricities show no effect, but simply hold each other in equilibrium. There is, however, in consequence of the intervening glass plate, an excess of electricity in B, as shown by the electrometer placed in connection with it; but a similar electrometer placed in connection with C gives no such indication. If now the plates are separated, both electrometers will diverge, as they should do, because the two electricities no longer hold each other in equilibrium. In this condition the electricity of the two plates may be tested and shown to be opposite. If a rod of glass be rubbed with silk and brought near the electrometer upon B, it will be repelled, which indicates positive electricity; if it be brought near the electrometer on C it will be attracted, showing negative electricity.

The condenser may be discharged, or brought back to its neutral condition, in two ways—first, by suc-

cessive contacts, in which the discharge takes place slowly, or by connecting the plates B and C by a conductor, in which case the discharge is instantaneous. If the plate C is touched no electricity is drawn off, because all that it contains is held in equilibrium by the plate B. If, however, the plate B is touched, all its free electricity—that is, all which is not neutralized—is drawn off. After this, a certain unneutralized portion of electricity will exist on C, which will be indicated by the electrometer. By continuing to touch the plates alternately the whole charge may be drawn off in small quantities. To obtain an instantaneous discharge we might touch one plate with one hand, and the other with the other hand, when the two fluids would flow through the body and neutralize each other. This produces a shock, and to avoid this we make use of a discharger.

Two circumstances limit the amount of electricity that may be accumulated in a condenser. First, the unbalanced electricity in the plate B goes on augmenting with the charge until at last its tension equals that of the prime conductor, after which no more can flow into the condenser from the machine. Secondly, the two electricities on the plates C and B tend to unite with an energy which goes on increasing with the accumulation of electricity on the plates, and may become so great as to break through the glass, and thus cause a union of the two fluids.

Heat Developed by Electricity.—The passage of electricity from one body to another is generally attended with an evolution of heat sufficient to inflame gunpowder, melt and even volatilize metals. The temperature of a good conductor of sufficient size is not, however, much affected by the transmission of a current of electricity; but if the size be dispropor-

tionate to the quantity passing over it, it will be heated to a greater or less degree. A number of interesting experiments may be performed to illustrate these facts. To convey strong charges of electricity,—

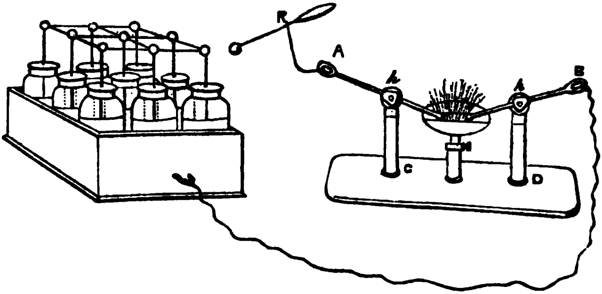


FIG. 50.

The universal discharger (*Fig.* 50) should be employed. It consists of two glass standards, C and D, through the top of which two brass wires, A and B, slide freely. These wires are pointed at the ends, but have balls which either slide or screw on according to use. The other ends are furnished with rings, and move or hinge at *h h*. The balls rest on a table of boxwood, into which a slip of ivory is inlaid across the diameter, about one inch wide. To melt a thin wire we attach it to the two knobs of the discharger; then connect B with the extreme surface of an electrical battery. By means of an insulating rod, R, we complete the circuit; and if the wire is fine enough, it will be instantly melted into globules, or volatilize. Gunpowder and other bodies may be inflamed in the same way.

Disruptive Discharge.—The return of a charged Leyden jar to its normal state constitutes an electrical

discharge, and is exactly opposed to insulation. This return to the normal condition may be effected in a variety of ways, and therefore constitute different kinds of discharge. The most violent form, termed disruptive discharge, is when a communication is made, by means of a discharger, with the internal and external coating of a Leyden jar. This discharge is attended with the sudden evolution of light and heat, and great expansive force. The distance through which the disruptive charge has been obtained, as between the metallic knob of the jar and the metallic knob of the discharger, is called the striking distance, or length of the spark (in a single jar it is about an inch); and this depends not only on the intensity of the charge, but the form of the conductor. The larger the conductor, the greater the electrical charge required to pass through a given distance, because *the intensity is diminished in the inverse ratio of the square of the conducting surface.* Long sparks produced from the knob of a prime conductor, or an arrangement of jars, may be a foot or more in length. These discharges are attended with lateral divergence, the flashes are of a violet colour, and are very beautiful. The character of these flashes depends almost entirely on the form, area, and electrical intensity of the discharging surfaces, also on the kind of electricity on the conductor in which the spark or flash originates. If we diminish the surface of the knob on the prime conductor until we arrive at a metallic point projecting freely into the air, a very curious result follows. Instead of a brilliant explosion we have bushes or stars of light, attended by currents of air. If a short brass rod with a rounded end project from the prime conductor of a powerful machine, it will send out a full brush of luminous rays, especially if a flat, imperfect conductor be held in front of it.

Faraday considers these phenomena as variations of disruptive discharge. One is called BRUSH DISCHARGE, which is due to a number of small, distinct, and successive explosions, which terminate like a short conical brush.

The glow discharge is an almost continuous result, depending on the portions of air in contact with the surface of discharge becoming charged with electricity; and if the machine be powerful, a sort of phosphorescent glow covers the whole surface of the prime conductor. The rarefaction of the air on the presentation of a pointed conductor forms this glow; but the condensation of the air, and the presentation of large rounded surfaces, will convert the glow discharge into a brush discharge. The influence of pointed conductors on electrically charged bodies attracted the attention of Franklin. He showed that, on presenting an uninsulated iron needle to the surface of an iron ball, its attractive force on a small thread immediately ceased. He also observed that this influence of a point in conducting off the electricity was attended with a current of air from the point sufficient to set in motion small models turning on a central axis, fitted up with cardboard vanes. A number of experiments will illustrate these facts.

Accumulation of Electricity on the Surface.—When electricity is communicated to a conducting body, it resides merely upon the surface and does not penetrate to any depth within. From a number of experiments intended to illustrate this fact we select the one first performed by Coulomb.

If a solid globe of metal, suspended by a thread of raw silk, or supported on an insulated glass pillar, be highly electrified, and two thin, hollow caps of tinfoil

or gilt paper, with insulating handles, as represented in *Fig.* 51, be applied to it, and then withdrawn, it will be found that the electricity has been completely taken off the sphere by means of the caps. An insulated hollow ball, no matter how thin its substance, will contain a charge of electricity equal to that of a solid ball of the same size, all the electricity, in both cases, being distributed on the surface. When the electric fluid is accumulated on the surface of a body, it tends to escape with a certain force which is called its TENSION, and the tension increases with the amount of electricity accumulated. So long as it does not exceed a certain limit it is held by the resistance of the air, but if the tension exceeds this limit the electricity escapes with a crackling noise and a brilliant light, called the electric spark. In damp weather the tension is always feeble, because the electricity is slowly carried away by the moisture of the air. In a vacuum there is no resistance to the escape of the electricity, and the tension is nothing. The electricity in this case flows off as fast as generated. If we suppose electricity to be a force exerted by an elastic fluid capable of compression, like air, it would exhibit a certain amount of tension or reactive force, which would be as the density of the number of particles confined in a given space. The term tension may also be applied to the polarized particles between two conductors, and to a state of induction generally. When the particles of a body are forced from their neutral state into new electrical conditions, they are, as it were, in a constrained position, and this may be

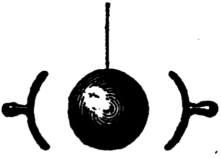


FIG. 51.

conceived to go on increasing up to its maximum limit.

Intensity is somewhat different to tension, although there would be nothing incorrect in speaking of the intensity of tension, or the reactive force, as indicating its higher or lower degree, just as we speak of the intensity of light and heat; but in its application to electrical phenomena it expresses the activity of an electrified conductor, as shown by the electrometer. Thus the charge communicated to a battery may be taken by a quadrant electrometer, which expresses the intensity of the charge; and we speak of a jar being charged to a given intensity, and this is as the square of the accumulated quantity of electricity.

Influence of Form.—The shape of a body also exercises a great influence in the distribution of electricity over the surface. If a body is spherical the electricity is distributed equally over the surface, as we have seen in the experiment with the two thin metallic hemispheres. To remove these hemispheres was to take away the surface of the sphere; and since by taking away the hemispheres all the electricity is taken away, we have proof that the electrical charge was entirely at the surface.

In an electrified sphere the same amount of attraction is shown for a pith ball, no matter where the contact is made on the surface, and this may be shown by an experiment called the Proof Plane, which consists of a small disc of gilt paper fixed at the extremity of an insulated thread of shellac or glass. The length of this stem, and of the support by which it is sustained, are so calculated that the small disc may supply the place of the fixed ball in the torsion balance apparatus, and act like it, when electrified, either upon the disc or the ball fixed at the extremity of the moveable

needle. A point of the surface of a body is touched by the proof plane, and if this point be electrified it is immediately perceived, because the proof plane, when carried to the balance, immediately acts on the moveable needle. By this mode we can prove that a hollow metal sphere does not present the slightest trace of electricity on its inner surface, even when its outer surface is strongly electrified. When a body is elongated or pointed, like a cone supported in a horizontal position, different results are obtained with the proof plane, which show that the pointed end is more highly charged than the other extremity of its surface. As a general rule, it may be stated that the nearer any surface approaches to a point the greater will be the accumulation of electricity at that point. This shows that electricity tends to accumulate or flow towards the pointed portions of bodies. This accumulation at points gives rise to a high tension, which overcomes the resistance of the air, and escapes. All pointed metallic bodies soon lose the electricity imparted to them, and often the escaping current can be felt by placing the hand in front of the point. If the flow takes place in a darkened room a feathery jet of faint light is observable. This power of points was early noticed by Franklin, and made use of in the construction of lightning conductors.

Atmospheric Electricity.—The complete identity between lightning and the electric spark was first shown by Franklin. The existence of electricity in the atmosphere is not confined to clouds, for it often exists when no trace of clouds is visible. In this case the electricity is positive. It is most abundant in open spaces, and at considerable elevations. Mr. Crosse gives the following results of his observations:—

1. The electricity of the air is almost always posi-

tive; increases after sunrise, diminishes towards noon, increases again towards sunset, and then decreases again towards night, after which it again increases.

2. The electrical state of the apparatus is disturbed by fogs, rain, hail, sleet, and snow. It is negative when these first approach, and then changes frequently to positive, with subsequent continued changes every few minutes.

3. Clouds also, as they approach, disturb the apparatus in a similar way, and produce sparks from the insulated conductor in rapid succession, so that an explosive stream of electricity rushes on the receiving ball, which it is wise to let pass off into the earth. Similar effects frequently attend a driving fog and a smart, heavy rain.

The principal causes which are supposed to produce electricity in the atmosphere are evaporation from the earth's surface, chemical changes which take place on the earth's surface, and the moisture, condensation, expansion, and variation of temperature in the air.

The electrical conditions of a thunder storm may be studied in the electrical conditions of a Leyden jar. The atmosphere becomes a great coated plane, or fulminating square, of which the charged cloud is the insulated and the earth's surface the uninsulated terminating conducting planes. The phenomena of thunder and lightning are due to the disruptive discharges through the intervening stratum of air. The grandeur and magnitude of the effect depend on the tension. The same phenomena attending many electrical experiments may also be observed. Thus lightning is often of a wavy, crooked, or zigzag appearance; at other times it is straight and brilliant, or spreading out in sheets; and sometimes it is globular, having the appearance of a ball of fire.

The return stroke is a violent and often fatal stroke felt by men and animals at a considerable distance from the place where the lightning strikes. This phenomenon is due to the inductive influence exerted by an electrified cloud upon bodies beneath it, which are all in an opposite electrical condition to that of the cloud. Now if a discharge takes place at any point, the cloud returns to its neutral state, induction ceases instantly, and all the bodies electrified by induction instantly return to a neutral condition. The suddenness of this return is what constitutes the return stroke. We may illustrate the return stroke by placing a living frog near an electrical machine in operation. Every time the machine is discharged, by placing the finger on the prime conductor, the frog experiences a shock, which is nothing else but the return stroke.

A lightning conductor is a rod of metal placed upon a building or a ship to shield it from the dangerous effect of lightning. A lightning conductor may be of harm if the rod be broken or zigzag. The electric fluid, obstructed in its passage, may damage the building. If the rod be not large enough it will melt.

The rod, then, should be of sufficient size. A copper rod of half an inch diameter, or an iron rod of three quarters, is large enough for any building.

If made of several pieces they should be most carefully screwed or welded together, so as to avoid defective parts. It should terminate a few feet above in a single platinum point, that it may not be fused or injured by rusting. The rod should pass into the earth till it meets with a layer of moist earth or a hole filled with coke. The lower end should branch off in two or three points from the building. It should be attached to the building with porcelain or glass fastenings. It was thought by Franklin that the

utility of a lightning conductor was due to the drawing off the electricity from the cloud and conducting it to the earth. The true explanation, however, is just the reverse. The cloud acts by induction on the earth, repelling the electricity of the same kind as that in the cloud, and attracting the opposite kind, which accumulates under the cloud. Now by arming a body with metallic points communicating with the earth, we permit a flow of electricity from the earth to the cloud. This flow not only prevents the accumulation of electricity upon the body, but it also tends to neutralize the electricity of the cloud, and thus the rod acts in two ways.

RÉSUMÉ.

The Leyden jar is so called from the town of Leyden, where it was invented by Muschenbrock. The metallic coatings are called the external and internal armatures. It is charged by connecting one of the coatings with the earth and the other with the source of electricity. When it is held in the hand by the external coating, and the knob connected with the prime conductor of an electrical machine, positive electricity accumulates on the inner and negative on the outer coating; but if the jar is held by the knob, and the external coating presented to the machine, the reverse condition takes place.

An electrical battery consists of a series of Leyden jars whose external and internal coatings are respectively connected with each other. The jars are usually placed in a wooden box, lined on the bottom with tin-foil, which connects the external coatings, which are also connected with two brass handles on the sides of the box. The internal coatings are connected with

metallic rods, and the battery is charged by placing the internal coatings in connection with the prime conductor. The external coatings are connected with the ground by a chain from the metallic handles. In discharging the battery the outer coating should be touched first, and for large batteries great care is required.

A condenser is an apparatus for condensing a large quantity of electricity on a comparatively small surface. Its action depends on the influence of induction, and essentially consists of two insulated conductors separated by a nonconductor. The theory of the Leyden jar is identical with that of the condenser.

The distribution of electricity depends on the extent of surface of a body and not on its mass. This may be shown by experiments with insulated hollow metallic spheres.

Atmospheric Electricity.—The atmosphere always contains free electricity, sometimes positive, sometimes negative. The electricity of the ground, according to Peltier, is almost always negative. In general the clouds are always electrified, either positively or negatively. The lightning discharge is an electric discharge which strikes between a thunder-cloud and the earth. The latter, by the induction from the electricity of the cloud, becomes charged with an opposite electricity; and when the tendency of the two electricities to combine exceeds the resistance of the air, the flash passes. Lightning generally strikes from above, but ascending lightning is sometimes seen. This is the case when the clouds are negatively and the earth positively electrified.

Voltaic Electricity.—It has been mentioned that chemical action is a source of electricity. The form of electricity thus developed is different, but its nature is the same as that due to friction. No chemical action can take place without disturbing the electric equilibrium of bodies and the development of free electricity.

If a piece of zinc is immersed in dilute sulphuric acid, chemical action immediately commences. The water is decomposed, the hydrogen of the water escapes in the form of gas, and the oxygen unites with the zinc. If the zinc be amalgamated with mercury the decomposition of the water is arrested, and only those particles in immediate contact with the amalgamated surface are affected. Small bubbles of hydrogen attach themselves to the sides of the plate, and this gaseous coating prevents the metal from being further acted upon by the acidulated water.

If a piece of copper be introduced into the vessel, no change is observable so long as the metals are kept apart, but the instant these plates are brought into contact a brisk action is set up. The hydrogen bubbles on the surface of the zinc go to the copper and rise to the top. These are succeeded by other hydrogen bubbles, all rising from the copper plate, as if that plate alone were subjected to this action. It is the zinc alone which is attacked, and this action continues so long as the acidulated water can act on the zinc plate, which is gradually converted into a sulphate of zinc.

It is not necessary that the metal plates should touch each other in the fluid. If only the lower parts are immersed and the upper ends connected with a wire, the liberation of these hydrogen bubbles will continue. This arrangement of plates is called a simple galvanic pair or element. It appears from this that two

dissimilar metals form a galvanic circle, and if the wire connecting the plates be cut in two, and the ends examined, the end coming from the copper plate will give indications of being charged with the same kind of electricity as that obtained by rubbing a glass rod (positive), and the zinc end will indicate electricity the same as that obtained on rubbed sealing wax (negative).

Voltaic Pile.—The first attempt to increase the power of a galvanic pair, by increasing the number of plates, was made by Volta. He constructed a pile of zinc and copper plates, with a moistened cloth interposed between them. He commenced with a zinc plate, upon which he placed a copper plate of the same size, and on that a circular piece of cloth, wetted with slightly acidulated water. On the cloth was laid another plate; then copper; then cloth, and so on till a pile of thirty or fifty plates was constructed. The terminal series at one end being copper, and at thè other end zinc, a metallic wire attached to the highest copper plate will be the positive pole, and the lowest zinc plate the negative pole.

In a pile which is insulated, one half is found to be electrified positively, and the other half negatively; the middle being neutral. The tension of the electricity at either end increases with the number of pairs of plates, independently of their size. The tension is greatest at the extremities, and these extremities are called poles, and the wires which are attached at the two poles for completing the circuit are called electrodes. So long as these electrodes are separated the pile shows no action, but on being brought together a spark is seen to pass, which arises from the recombination of the two electricities. This spark does not discharge the pile, as in the case of a Leyden jar, but a continual succession of sparks may be observed,

showing that decomposition is kept up in the pile. If the two wires are actually connected the sparks cease, but the action is still going on, and this continual flow of electricity is called an electric current. According to the two-fluid theory, there are, in fact, two currents flowing in opposite directions; but it is found convenient to consider only one, namely that which flows from the positive to the negative pole.

A voltaic pile was rather an awkward arrangement. A number of metallic plates placed horizontally on each other would press out all the acidulated water, or other fluid, from the cloth by which these plates were separated, and so interfere with the action of the pile.

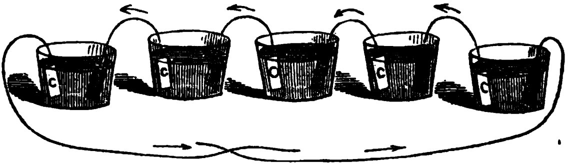


FIG. 52.

To avoid this, Volta introduced—

The couronne des tasses, or crown of cups, where glass vessels contained water acidulated with sulphuric acid, and the plates of copper and zinc were soldered to the ends of a bent wire or strip of copper, as shown in *Fig.* 52. When the circuit is closed by joining the ends of the wires, gas is actively evolved; but when the current is broken the evolution of gas ceases.

Daniel's Battery (*Fig.* 53) consists of an outer glass vessel, A, into which is placed an open cylinder of copper, with perforations in the side, and a perforated rim, or gallery, at E. A binding screw is

attached to the copper cylinder, C. Into this copper cylinder a porous cylinder, D, of earthenware is introduced, closed at the bottom. Into this porous cylinder a rod of amalgamated zinc, Z, is introduced, with a binding screw at the top. Instead of porous earthenware cells, an animal membrane may be employed, such as an ox gullet. A dilute solution of sulphuric acid is introduced into the porous tube, and the outer copper cylinder and glass are nearly filled with a

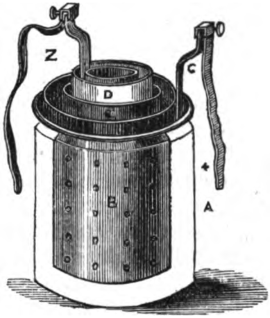


FIG. 53.

saturated solution of the sulphate of copper. Solid crystals of this salt rest on the rim E, which dip into the solution, and gradually dissolve as the battery comes into action. When a connection is made between the rod of zinc and the copper cylinder, electrical action commences. The oxygen of the acid solution combines with the zinc, and the liberated hydrogen passes through the porous cells to the copper. It does not escape in the form of gas, but enters into combination with the oxygen of the sulphate of copper; and the metal, being thus deprived of its acid, is reduced to its metallic state, and deposited on the interior of the

copper cylinder. By the continual absorption of hydrogen and the deposition of metallic copper a bright conducting surface is maintained, which not only increases the intensity, but secures greater steadiness of action. In ordinary batteries the escape of hydrogen is not only very disagreeable, but it prevents contact between the fluid and the metal, and causes the zinc to be deposited on the copper. When this occurs, not only is a portion of the surface rendered useless, but counter currents are set up from a number of small batteries formed on the surface, which more or less neutralize and diminish the effect of the battery. The constancy of action peculiar to the battery just described has obtained for it the name of the constant battery. When the battery is not in use the zinc rod is taken out and wiped; the membranous bags or porous cells are emptied of their solution, filled with water, and suspended from a wooden frame. A battery formed of ten copper cells, 20 inches high and $3\frac{1}{2}$ in diameter, and zinc rods $\frac{5}{8}$ in diameter, will maintain a piece of platinum wire, $\frac{1}{30}$ in diameter, 6 inches long, at a red heat, and liberate 12 cubic inches of the mixed gases per minute.

Grove's Battery.—A very excellent constant battery has been invented by Mr. Grove, and is one generally used for purposes which require strong galvanic action. *Fig.* 54 represents a section. A B C D is a trough of stoneware or glass, divided into compartments by the partitions E E E, which make four acid-proof cells. The dotted lines represent porous cells of unglazed porcelain or pipeclay, and so much smaller than the cells as to allow about double the quantity of liquid that is contained between the outer surfaces of the porous cells and the earthenware cells. The four central lines, 1, 2, 3, and 4, are plates of

amalgamated zinc, and the lines which bend under the porous vessels are sheets of platinum, which are fixed to the zinc plates by small clamp screws. Dilute sulphuric acid is poured into the porous cells, into which the zinc is placed; and outside the porous cells,

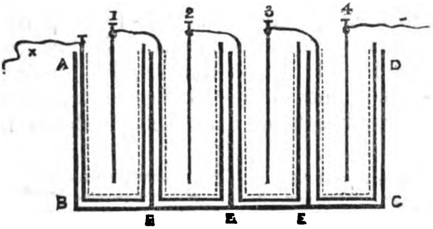


FIG. 54.

in contact with the platinum plates, is concentrated nitro-sulphuric acid, formed by equal mixtures of the two acids some time before used. During the action of this battery there is an abundant evolution of nitrous acid gas, and this is absorbed by covering the battery with an apparatus containing quicklime.

With a battery of this kind, consisting of four pairs of plates, and each zinc and platinum plate having a surface of 14 square inches, and the whole occupying a space of not more than a cube of 4 inches, Mr. Grove liberated 6 cubic inches of mixed gas per minute, and raised a platinum wire of $\frac{1}{40}$ in diameter, and 7 inches long, to a red heat; and ordinary metal wires are melted into globules.

When the battery is first put into action, by uniting its poles, the nitric acid becomes first yellow, then green, then blue, and ultimately hydrogen is evolved from the surface of the platinum plates. The oxide of zinc does not pass through the porous cells, but

remains on its own side, which keeps a clean surface, and maintains the energetic and constant action of the battery.

Bunsen's Battery.—The thinness of the platinum plates in the battery just described renders them liable to fracture ; and their high price is also another objection to their general use. M. Bunsen, therefore, substituted for the platinum plates hollow cylinders of carbon, baked in iron moulds, by making coke, reduced to a fine powder, cohesive with molasses. The battery thus made has the cylindrical form of

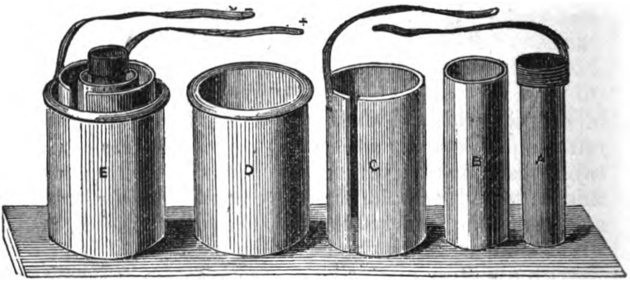


FIG. 55.

Daniel's battery, from which it differs only in having the hollow cylinder of copper replaced with a hollow cylinder of carbon ; pure or dilute nitric acid is used instead of the sulphate of copper solution ; and porous cylinders of earthenware must be substituted for animal membrane. The accompanying *Fig.* (55) shows the several parts of one of the cells of a Bunsen battery. A is the carbon cylinder. Each of these cylinders is furnished at the upper end with a copper ring, carrying a band for connection, which is put in

contact with a similar band carried from each zinc cylinder, and secured by clamps. The copper ring should rise sufficiently above the glass vessel, so as not to touch the nitric acid; but with every precaution, a portion will rise through the pores of the charcoal and alter the interior of the copper ring, and this should be well washed and cleaned every time the battery is used. B is the porous cell, into which is introduced C, the cylinder of amalgamated zinc that surrounds the porous cell: D, the external glass or earthenware jar. E represents the entire arrangement of the cell.

When the extremities or poles of a battery are examined with an electrometer they are found to be positive and negative, the gold leaves of the instrument repelling each other at the same pole and attracting each other at different poles, even when a small space of air intervenes. Hence frictional electricity differs from voltaic electricity, in having a much greater elastic force, or a much higher intensity. Voltaic electricity differs from frictional electricity in the great quantity of electricity which is developed and put in motion, and in the continuity or perpetual reproduction of the current. Dr. Faraday has said that the chemical action of a grain of water upon four grains of zinc can evolve electricity equal in quantity to that of a powerful thunder storm, and that the quantity of electricity in 25¼ grains of water is equal to above 24,000,000 charges of an electrical battery, charged each time with 30 turns of a large and powerful plate machine in full action.

When a battery is in a state of activity by connecting the poles, and wires of different metals be introduced between the poles, so as to complete the circuit, the current passes through the interposed metals with different degrees of resistance; and the same occurs

with reference to the conducting power of water holding in solution different acids, alkalis, or salts. The conducting power increases according to the quantity of salts dissolved, but more slowly when the solution is nearly saturated.

The tension of a battery may be regarded as the tendency of the accumulated electricity to free itself, and overcome the resistances offered by the bodies through which it is conducted. The *tension* of a battery depends on the number of couples, while the *quantity* depends, other things being the same, on the surface of the plates. The larger the surface the greater is the quantity of electricity which flows through the circuit. In most cases the tension at the extremities of a battery is far weaker than in electrical machines (except when a very large number of couples is employed). Neither of the extremities of a battery will give a spark or attract light bodies, and it is only by a delicate gold-leaf electroscope that the tension can be indicated. In this experiment one of the leaves of the electroscope must be connected with one end of the battery, and the other with the earth. The battery is put into action, and on breaking the communication the leaves diverge. A Leyden jar may be charged by connecting the interior coating with one end of the battery, and the external coating with the other, but the charge is always feeble.

Intensity and Direction of Currents.—The two electricities, when liberated by the chemical action of a battery, tend to reunite and form a neutral fluid, by entering into the conducting bodies in their vicinity. The quantity of electricity which remains free constitutes the tension of the battery or the intensity of the current. When the two extremities of the battery are united by a metallic arc, the tension at first diminishes,

but this diminution becomes slower and slower till it reaches its limit, beyond which the tension no longer decreases.

The direction and intensity of a current will depend on the degree of chemical action exerted by the liquid on the metal most liable to oxidation. When the liquid and the metals are known, the direction of the current can be inferred. The metal most acted upon by the liquid takes from the liquid negative electricity. Zinc is more attacked by an acid solution than copper, and therefore takes from the solution its negative electricity; but if we have a solution of sulphide of potassium, which affects the copper more than the zinc, then the order will be reversed; the copper will take negative electricity from the solution, and the current will have an opposite direction. In a battery of zinc and copper plates with an acid solution, the zinc extremity will give positive electricity; in a battery of the same kind with a solution of sulphide of potassium, it will give negative electricity.

Chemical Effects.—In 1800, Nicholson, by means of a voltaic pile, decomposed water. With a voltaic pile the operation is rather tedious, but with four or five Bunsen's cells the decomposition is very rapid. Pure water is not a good conductor, and a little sulphuric acid is added to increase its conductibility. In a simple piece of apparatus two glass test-tubes are filled with water and inverted over the two platinum electrodes of the battery. On completing the circuit, gas bubbles rise to the surface, and accumulate at the top of the test-tubes. The volume of gas liberated at the negative pole (hydrogen) is about double that liberated at the positive pole (oxygen). This experiment determines the quantitative and qualitative composition of water.

Electrolysis is the decomposition of bodies by means of a voltaic current. The positive electrode is called the *anode*, and the negative the *kathode*. Bodies which had been regarded as simple have been decomposed by means of powerful batteries. Davy proved that soda and potass were the oxides of unknown metals, sodium and potassium. The decomposition of binary compounds is analogous to that of water; one element goes to the positive and the other to the negative pole. The bodies which go to the positive pole are called *electro-negative* elements, because at the moment of isolation they are considered as charged with negative electricity, while those separated at the negative pole are for a similar reason called *electro-positive* elements.

Decomposition of Sulphate of Potass (KSO_4).—The decomposition of salts may be easily shown with a glass tube bent, U. This tube is nearly filled with a saturated solution of a soda salt, coloured with blue litmus. The platinum electrodes of about four of Bunsen's elements are then placed in the two limbs of the bent tube. In a few minutes the liquid in the positive limb becomes red, and in the negative limb green. This shows that the salt has been decomposed into an acid, which has gone to the positive pole, and a base, which has gone to the negative pole; and these colours are precisely what is obtained by the action of a free acid and a base on litmus paper. In a solution of sulphate of copper ($CuSO_4$) the acid and oxygen gas appear at the positive electrode, and metallic copper at the negative electrode; and similarly nitrate of silver ($AgNO^6$)—the silver goes to the negative and the acid and oxygen to the positive electrode. This decomposition is generally expressed by saying the acid is

liberated at the positive electrode and the base at the negative.

Electro-plating.—The decomposition of salts by a battery has been applied to the art of precipitating metals from their solutions by the slow action of a voltaic current.

To take a copper cast a bath is filled with a saturated solution of sulphate of copper. Two brass rods pass across, and rest on the ends of, the bath. One of these rods is connected with the positive and the other with the negative pole of a Daniel's element. From the rod connected with the negative pole is suspended the mould, and from the other rod a plate of copper. The current is now closed, the salt is decomposed, the acid is liberated at the positive pole, while copper is deposited on the negative mould. If the bath be large enough, several moulds may be suspended at the same time. In about forty-eight hours the mould is covered with a solid layer of copper, which can be easily detached from the mould. If the cast be taken from plaster, which is usually the case, it must first be immersed in a bath of melted wax, and quickly withdrawn. The rapid drying of the wax after withdrawal arises from the absorption of stearine by the plaster. When cooled it is coated carefully and thoroughly with graphite, or black lead, by means of a soft camel's hair pencil. A strip of cartridge paper is then passed round the edge, and some melted stearine is poured upon it: on cooling, this gives a hollow cast of the original medal. This is prevented from adhering to the plaster by the black lead. It is then removed and covered with black lead, to present a conducting surface. The mould so prepared is suspended from the negative pole of the battery. Very good moulds may be obtained by gutta-percha, which

are prepared in a similar manner. The copper plate suspended in the bath not only closes the circuit, but keeps the solution in a state of concentration.

Electro-gilding was formerly done by means of an amalgam of gold and mercury, which was applied on the metal to be gilded, which was afterwards heated in a furnace sufficiently to volatilize the mercury. The work was most unhealthy and expensive, and it has been entirely superseded by electro-gilding and electro-silvering. The objects to be gilded or silvered are first heated, so as to remove all the fatty matter which has adhered in previous processes. As the objects to be gilded are usually copper, the surface in heating becomes covered with a film of the protoxide of copper. This is removed by another process. The object, while still hot, is immersed in a bath of dilute nitric acid, to remove the oxide. It is then rubbed with a hard brush, washed in distilled water, and carefully dried in heated wood shavings. To remove any spots which appear, the object is rapidly immersed in ordinary nitric acid, and then in a bath which consists of a mixture of nitric acid, bay salt, and soot. When the object has been so prepared it is attached to the negative pole of a battery consisting of three or four elements of a Bunsen's or a Daniel's, and immersed in a bath which consists of one grain of chloride of gold, 10 grains of cyanide of potassium, dissolved in 200 grains of water. This mixture varies with different firms. To keep the solution concentrated a piece of gold is suspended from the positive electrode. This method will gild copper, silver, bronze, brass, and nickel. Iron, tin, zinc, lead, and steel are difficult to gild. To obtain a good coating on these metals they are first covered with copper.

Electro-silvering is exactly similar, except in the composition of the bath, which usually consists of two parts of cyanide of silver, two parts of cyanide of potassium, dissolved in 250 grains of water.

Polarization and Transfer of the Elements of the Liquid.—Powerful chemical action is not alone sufficient to produce a powerful voltaic effect. All the metals are good conductors of electricity, and when they combine to form alloys they often give evidence of intense chemical action; but the voltaic effect is often very small. If a glass tube in the form of a U be taken, and a small quantity of tin melted by means of a spirit lamp; and if the wire of a galvanometer be introduced down one limb of the tube into the melted tin, while in the other limb of the tube the platinum wire connected with the other extremity of the galvanometer be introduced, the platinum will unite with the tin; but after the first instant of contact no permanent deviation of the needle will be observed, although the chemical action continues for some time. In order that the liquid shall have the power of exciting voltaic action, it must be a liquid capable of decomposition by one of the metals. This necessity of a compound liquid for exciting the force appears to arise from the necessity of peculiar polarization in the liquid in order to transmit voltaic action. In all voltaic actions the transfer of power is effected by a polar influence propagated through the liquid and solid particles of the current, and the chain of the conducting material must be continuous throughout, so that the force may circulate. This process of polarization may be conceived to occur in the following manner, which offers an explanation of the manner in which the platinum, or other metal analogous to it, may be supposed to act:—

When a plate of pure zinc or of amalgamated zinc is immersed in a compound liquid which is capable of attracting it chemically, the metal at the points of contact becomes positively electrified, whilst the distant portion becomes negative. The layer of liquid in contact with the zinc undergoes polarization, which affects each molecule of its chemical constituents. If dilute hydrochloric acid (HCl) be used, the particles of chlorine become negative, and the particles of hydrogen positive; but in this condition there is no communication between the negative particles and the

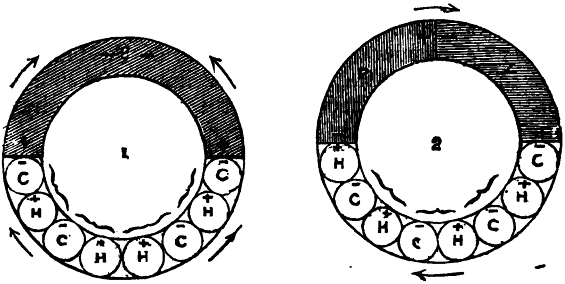


FIG. 56.

positively electrified particles of hydrogen: consequently, beyond the production of this state of electrical tension, no change takes place. This condition may be represented by *Fig.* 56 (1).

But the condition is entirely altered if a plate of platinum be introduced, or some metal not so easily acted on by the acid, and made to touch the zinc. By contact with the zinc the platinum becomes polarized; it imparts a portion of positive electricity to the zinc, and receives a portion of negative electricity in return, and transmits the polar action to the liquid. A chain

of polarized particles is thus produced, as in (1). The chlorine of the particle of HCl nearest the zinc becomes negative, under the influence of the chemical affinity which exists between it and the zinc, and the hydrogen becomes positive. The second and third particles of the acid become similarly electrified by induction; but the platinum, under the influence of the induction of the zinc, being negative, is in a condition to take up the positive electricity of the contiguous hydrogen (2). The action now rises high enough to enable the zinc and the chlorine to combine chemically, forming chloride of zinc, which is dissolved by the liquid and removed from further action; but the particle of hydrogen nearest the zinc now seizes the oppositely electrified particle of chlorine which lies next to it, and a new portion of HCl is reproduced, whilst the hydrogen in the second particle of the acid is transferred to the chlorine of the contiguous particle, and the particle of hydrogen which terminates the rim is electrically neutralized by its action upon the platinum, to which it imparts its excess of positive electricity, and immediately escapes in the form of gas. Fresh particles supply the place of those which have been decomposed; and in this way a continuous action is kept up. The transfer of electricity from particle to particle of the liquid is attended with a transfer of the constituents of the liquid in opposite directions. These changes, when continued uninterruptedly, constitute what is called a voltaic current; but this word current is merely a convenient expression. In every voltaic current it is assumed that a quantity of negative electricity equal in amount to that of the positive is set in motion, and proceeds along the conducting medium, or wire, in a direction opposite to that in which the positive is moving; and it is

supposed that by the continual separation and recombination of the two electricities in the wire its heating and other effects are produced. In order to avoid confusion, when the direction of a current is mentioned, the direction of the positive current is alone indicated.

The best arrangements do not develope the whole of the force which results from chemical decomposition. The causes which obstruct the development of electricity in a current have been investigated by Professor Ohm, who has reduced them to a mathematical formula.

The free development of electricity is resisted by the affinity of the elements of the liquid, which tend to resist decomposition; the imperfect conduction of the fluid; and the resistance of the conducting wires.

Ohm's Formula.—The intensity or electro-motive force, I, of a current in a closed circuit is directly proportional to the sum of the electro-motive forces, E, which are in activity in the circuit, and inversely proportional to the sum of the resistances of all parts of the circuit, or R; that is,—

$$I = \frac{E}{R}$$

By the expression "electro-motive force" is meant the force or forces or causes which produce an electric current; and by the term "resistance," all the obstacles opposed to the passage of the current by all parts of its circuit. This resistance is the inverse of the conducting power of all the parts of the circuit. The resistance which is the sum of all the resistances may be represented by the length of a wire of a given kind and thickness, which Professor Ohm calls its reduced length.

The following laws have been deduced from this formula :—

1. The electro-motive force varies with the number of elements in any voltaic circuit, with the nature of the solids or fluids of which each element is composed.

2. The resistance of each element is directly proportional to the distance of the plates from each other in the liquid, and to the specific resistance of the liquid, depending on its chemical constitution; and inversely to the surface of the plates in the liquid.

3. The resistance of the wire connecting the poles of the circuit is directly proportional to its length and its specific resistance, and inversely to the area of its section.

RÉSUMÉ.

Voltaic Electricity.—If a plate of copper and a plate of zinc be immersed in dilute sulphuric acid chemical action commences, which is attended (as all chemical action is) with a disturbance of the electrical equilibrium. If the plates be connected with a metallic band or wire the chemical action is greatly increased. The opposite electrical conditions of the two plates discharge themselves, and the direction of the current in the connecting wire is assumed to be from the copper plate to the zinc plate, the direction in which the positive electricity is supposed to flow. Such an arrangement of two plates would be called a simple voltaic element or couple.

The voltaic pile consists of a series of discs of copper and zinc, separated from each other by means of a cloth moistened with dilute sulphuric acid.

Voltaic Battery. — To produce greater electrical

effects a number of voltaic elements or couples are joined together, so that the zinc of the one element is joined to the copper of the other.

Constant Batteries.—The currents produced by a voltaic pile, or battery, with a single liquid, rapidly diminish in intensity. These arrangements have gone out of use, and they have been replaced by batteries with two liquids. The only way to secure a constant current for any length of time is to prevent the polarization of the metal not acted upon by the liquid, or, in other words, to prevent the liberated hydrogen from being permanently deposited on the surface. This is obtained by placing the inactive metal in a liquid upon which the hydrogen can enter into chemical combination.

Daniel's battery was the first battery of this kind. The hydrogen resulting from the action of the acid on the zinc is liberated on the surface of the copper plate, where it comes into contact with a solution of the sulphate of copper, which is reduced into sulphuric acid and metallic copper. The strength of the copper solution is kept up by the crystals of sulphate of copper on the rim, which are gradually dissolved. The sulphuric acid passes through the porous cylinder or membrane, and replaces the acid used by its action on the zinc. As the quantity of acid liberated from the solution is constant, the action of the acid on the zinc is also constant; and by this arrangement a uniform current is maintained.

Grove's Battery. — The copper solution in the battery just described is replaced by nitric acid, and the copper by platinum; the hydrogen, which would be liberated on the platinum, comes into contact with the nitric acid, and decomposition takes place; water and hyponitrous acid are formed; the

acid fumes are partly dissolved, and partly escape with a very disagreeable odour, which is one objection to the battery.

Bunsen's battery is sometimes called the zinc carbon battery. It is a Grove's battery in which the platinum is replaced by a cylinder of carbon.

Tension of battery is the force by which the electricity tends to overcome the resistances offered to its passage.

Chemical Effects.—By means of voltaic electricity many chemical compounds may be decomposed. The bodies separated at the positive pole are electro-negative, and those at the negative pole electro-positive; but the same body may be either electro-negative or electro-positive, according to the body with which it is associated. Sulphur is electro-negative towards hydrogen, but electro-positive towards oxygen.

Electrolysis is a term applied by Dr. Faraday to decompositions by voltaic electricity. The bodies susceptible of decomposition are called electrolytes. The force required to decompose substances varies with different bodies, and in all cases they must be in solution.

Polarization and Transfer of Elements.—In all voltaic action the force is transmitted by the polarization of the particles through which the current is propagated. The sheet of liquid in contact with the zinc in a voltaic couple undergoes polarization, which affects each particle of its chemical constituents, and a chain of polarized particles is thus produced. In order that a liquid should be capable of exciting voltaic action, it must be a liquid capable of decomposition by one of the metals in which it is immersed.

Ohm's Formula.—The intensity of an electric current, when a battery is in action, is directly as the whole

electro-motive force in operation, and inversely as the sum of all the impediments to conduction. It may, therefore, be expressed by a fraction whose numerator is the electro-motive force, and its denominator the sum of the resistance of all its parts. Let I be the intensity of the current, E the electro-motive force of the battery, R the constant resistance, and r the variable resisting influence in the connecting wires. Then for a simple voltaic couple,—

$$(1) \quad I = \frac{E}{R + r}$$

The intensity of a current from a battery with couples will be,—

$$(2) \quad I = \frac{n\,E}{n\,R + r}$$

Oersted's Experiment.—In 1819, Professor Oersted, of Copenhagen, published a work which connected magnetism with electricity. A very simple piece of apparatus will clearly illustrate the experiment. A copper wire is suspended horizontally in the direction of the magnetic meridian over a small magnetic needle. Now the wire and the needle are parallel to each other; but as soon as the ends of the wire are connected with the poles of a battery of a single voltaic couple or element, *the needle is deflected, and tends to arrange itself at right angles to the magnetic meridian, in proportion to the intensity of the current.*

We have throughout assumed, for convenience of illustration, that the current flows from the negative to the positive plate, and the student will do well to remember that,—

1. *If the current passes above the needle, and goes from south to north, the north pole of the needle is deflected towards the west.*

2. *If the current passes below the needle, also from south to north, the north pole is deflected towards the east.*

3. *When the current passes above the needle, but from north to south, the north pole is deflected towards the east.*

4. *The deflection is towards the west when the current flows from north to south below the needle.*

To remember the direction of the needle under the influence of a current, Ampère imagines the observer buried in the conducting wire, with the current entering at his feet and passing out at his head, and his face always turned towards the needle. In this position the north pole is always deflected towards the left of the observer. In this way the following general principle is obtained :—

The directive action of currents on magnets the north pole is always deflected towards the left of the current.

Action of Conducting Wire on a Magnetic Needle.—The activity of the wire which connects the two metallic plates of a battery may be conveniently studied by observing its influence on a magnetic needle freely suspended in a direction parallel to the wire. A needle so suspended tends to arrange itself at right angles to the direction of the current. If the wire and needle be arranged in the direction of the magnetic meridian, the deviation of the needle affords an approximate measure of the force which is conveyed by the wire. The movements of such a needle afford a delicate test of galvanic electricity, or electricity in motion.

Let A B be a conducting wire of a closed galvanic circuit, along which electricity is passing from A to B,

A——————————B

A being the positive end and B the negative end; then, if a delicate magnetic needle be suspended near A B, its direction will be changed. When the needle is above the wire A B, it will turn its north pole to the right; when the needle is below the wire it will turn to the left. When the needle is in the same horizontal plane as the wire its north pole is elevated.

The relation between the voltaic force and a magnetized needle is of such a nature that they deflect each other, and tend to a position at right angles to each other. For instance, if the galvanic force, which has been called a current, is moving from east to west, the position of equilibrium of the needle is in the direction of north and south; and if the strength or force of the current were rightly adjusted to the power and weight of the needle, and one or other of them were free to move, this relative position would be obtained. If, however, the needle be fixed and powerful, and the current move along a single wire so arranged as to be free to move, the current will carry the wire into a position at right angles to the needle. If, on the other hand, the needle be small and light, like a compass needle, while a strong current passes near it, along a stout fixed wire, the needle will be the moving body and take the crossed position. In either case the result is the same, the needle and the current tend to rest at right angles to each other. The direction which the needle takes follows a fixed and well-known law, being right or left according to the direction of the current. All you have to do is to observe

whether the current deflects the north end of the needle to the right or to the left, and you know at once the direction of the current.

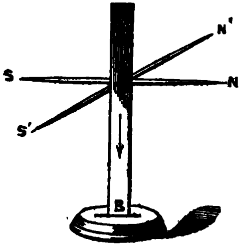


FIG. 57.

Let A B (*Fig.* 57) be a stout slip of copper, with a magnetized needle suspended behind it, and made to hang, when at rest, in a vertical position. If now a galvanic current is made to descend from A to B, the needle will be deflected into the position N′ S′, its north end moving to the right as you look in front of it. As the force of the current increases the deflection increases, until the needle attains a position at right angles to the current, at which position it will remain, no matter what further force may be given to the current. If the piece of copper was bent round at the bottom in the form of a U, and the current, instead of passing away at B, was carried upward, then the portion of the current ascending would act on the needle just as much as the current descending, so that the whole effect of the two currents is to increase the deflection of the needle.

The Multiplier.—By continuing this process—that is, by causing the current to pass many times about the needle—we increase the effect. This is accomplished by employing a copper wire, insulated with cotton or silk, and making several convolutions on a wooden frame. The length and thickness of the wire of which the multiplier is made will vary according to the uses to which it is applied. A short length of thick wire is used for strong currents, and a very long length of thin wire for feeble currents. A strong

current requires to be increased or multiplied fewer times, or to pass fewer times round the needle, than a weak current.

The instrument has usually a graduated circle, and the deflection gives an idea of the relative value of the two forces, and hence it has been termed a galvanometer. The sensibility of a galvanometer is further increased by placing outside the coil a second magnetic needle of like power, with its poles reversed. The directive force of the earth is then neutralized. A pair of needles so arranged constitute an astatic combination.

The astatic galvanometer is represented in *Fig.* 58. The needles, *n s*, *s n*, are suspended, one within the coil and one above it, by means of a fibre

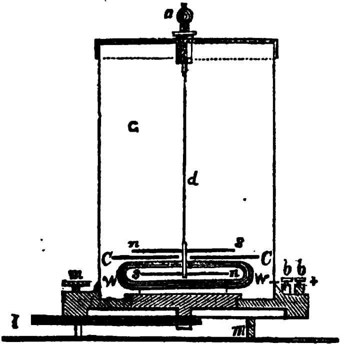


FIG. 58.

of fine silk, the whole being enclosed in a cylindrical glass case. The parallelisms of the needles are secured by connecting them together with a thin piece of copper wire. The fibre of the silk, being attached to

the upper extremity of the wire, *d*, by means of a screw at *a*, the point of suspension of the silk, can be either raised or depressed without twisting it, so that when the instrument is not in use the silk fibre is relieved of the weight of the needles. *C C* is a circular piece of copper, graduated on its outer margin, for observing the angular deviation of the needles. *b b* are little cups of mercury for connecting the two extremities of the coil with the wires which transmit the current. The apparatus is levelled by two screws on the under side; and the coil of wire is placed, by means of a lever, accurately parallel to the two needles, so as to make them coincide with the zero of the graduated circle. Such an apparatus will not only indicate the existence of voltaic action, but it will also measure its amount. When the deviations of the needle are small, say 15° or 20°, the number of degrees of deviation gives nearly the exact force; but for larger angles of deviation this is not the case, because the more the needle deviates from the parallelism of the coil, the more obliquely, and therefore the less powerfully, does the force act which occasions the deviation.

Thermal Influence.—We have mentioned, in page 120, that the passage of electricity is attended with the evolution of heat. Now the same effect is also produced when a voltaic current is passed through a metallic wire. A very powerful battery will melt thin wires of the most infusible metals, and rods of pure carbon have been so raised in temperature as to be softened and welded together. In mining operations a small wooden cartridge, containing powder, is covered, in some convenient position in the mine, with powder. In this wooden cartridge two thick insulated wires are inserted, and joined in the interior with a fine

iron wire. Two long wires lead to the terminals of a battery of sufficient strength. When the circuit is complete, the fine iron wire becomes incandescent and the powder in the mine explodes. In fine wires the thermal effect is most easily seen, but thicker wires are similarly influenced. By an apparatus rather too complex to describe in this work, called the *galvano-thermometer*, the thermal effect of electric currents has been established as follows:—

1. The heat disengaged is directly proportional to the square of the intensity of the current and to the resistance of the wire.

2. Whatever be the length of the wire, if the diameter remain the same, and the same quantity of electricity passes, the increase of temperature is the same in all parts of the wire.

3. For the same quantity of electricity the increase of temperature in different parts of the wire is inversely as the fourth power of the diameter.

If wires of the same size, but of different metals, such as platinum, iron, and silver, be interposed in the voltaic circuit, the platinum becomes most heated, because of its greater resistance. A number of interesting experiments may be shown by the teacher in illustration of this part of the subject.

Luminous Property.—When the circuit of a battery is closed, the point of contact frequently emits a spark of great brilliancy, and a similar result follows on breaking the contact. These effects are only obtained from powerful batteries.

Electric Light.—When two pencils of charcoal form the electrodes, and the terminals are connected with a battery, a most brilliant light is obtained. The two charcoal points are first placed in contact; the current soon raises them to incandescence; they are

then removed about one-eighth of an inch or more, according to the intensity of the current. An arc extends between the two points, of exceeding brilliancy, and is called the voltaic arc, and its length varies with the force of the current. One of the charcoal points is fixed, and the other is moved by means of a rack and pinion. When the light is used for purposes of illumination, the distance between the charcoal points must not alter, and the current must be constant. Without these conditions the light is not continuous. M. Duboscq has invented an apparatus to secure these conditions.

Conducting Wire.—If a piece of glass or other insulating body be introduced between the conducting wire and a magnetic needle, the deflection of the needle is not affected. The conducting wire not only affects a magnetized needle, but the wire itself displays magnetic properties. If a thin wire of some non-magnetic metal, say copper, be employed to complete a voltaic circuit, such a wire will, for the time, attract iron filings, and the filings will be arranged in a uniform thickness around the circumference of the wire. When the circuit is broken by disconnecting the wires, the filings fall, and the attractive power of the wire is instantly renewed on completing the circuit. The iron filings become small magnets, the poles of which are arranged alternately north and south around the wire.

Electro Magnets.—As every part of the wire along which a current is passing is magnetic, by coiling the conducting wire into a ring, a larger number of particles can be brought to act on a piece of soft iron introduced through the axis of the ring at right angles. When an electrical current flows through a metallic wire, it is everywhere surrounded by curves of mag-

netism placed in planes perpendicular to the direction of the current, and small magnetic needles, free to move, will arrange themselves at tangents to these curves. Hence the magnetic force emanating from the wire does not act in a line parallel to the current, but is exerted in a plane perpendicular to the wire.

If a piece of copper wire be wound in a spiral form round a glass tube, without allowing the wire to touch, the action of a very considerable length of wire may be concentrated on a piece of soft iron introduced through the axis of the coil. Very powerful temporary magnets may be constructed in this way. If the wire be insulated, so that the coils may be close to each other, the effect may be greatly increased by winding another series of coils over the first, and a second over the third, till a number of layers are coiled round the bar to be magnetized. In preparing an electro-magnetic coil the wire must be continuous, but it need not be coiled in one direction only. If the coils follow from left to right in the first coil, the wire, in winding backwards, will be from right to left. This is of no consequence, because the direction of the current is also reversed in this layer, so that the effect of the reversed twist is neutralized. A helix through which an electric current is passing is powerfully magnetic, the two forces accumulating at its opposite extremities. If the helix be supported with its axis in a vertical position, and a small rod of soft iron partially introduced within the coil, as soon as an electric current of sufficient power is transmitted through the coils, the bar will raise itself nearly equidistant between the extremities of the coil, the bar becoming, for a time, a powerful magnet; and the poles of the bar are, of course, the reverse of those of the coil by which its magnetism was produced.

The most powerful magnets are formed by pieces of soft iron being bent into the form of a horseshoe, and an insulating wire coiled several times round the iron. In this manner magnets have been constructed able to sustain a ton weight.

Electro-Magnetic Rotation.—We have mentioned that the deflective action of a conducting wire on a magnetic needle is a tangential one, or, in other words, the direction of the force is at right angles to the diameter of the wire. One pole of the needle is deflected to the right hand, and the other pole to the left; and on whatever side of the wire the needle is placed the same effect takes place. The tendency of this force, acting at every point of the circumference of the wire in the same direction, is to cause a rotation of the wire on its axis, and to communicate motion in an opposite direction to all magnets within its influence.

If the action of the current be confined to a single pole of the magnet, a continuous rotation of the pole round the conducting wire may be obtained; or if the magnet be fixed and the wire moveable, the wire will revolve round the magnet. The contrivance originally proposed by M. Ampère for causing a bar magnet to rotate on its own axis is very simple. The magnet, M (*Fig.* 59), is allowed to float in mercury, being kept in a vertical position by a weight of platinum, P.

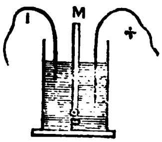


FIG. 59.

The action of the electric current is confined to one pole of the magnet by insulating the conducting wire, with the exception of its end, and introducing it vertically into the mercury to the depth of half the magnet. Another wire, connected with the negative pole of the battery, just dips into the mercury to complete the

circuit. The counter-action which would otherwise take place from the other pole is thus prevented, and the magnet turns slowly on its axis.

The wire may be shown to rotate by taking a glass tube, G G (*Fig.* 60), and closing the lower end with a piece of cork, through which a piece of soft iron wire is introduced, so as to project above and below. A little mercury is introduced, so as to make a passage between the wire and the glass tube. The upper opening of the tube is also closed with a cork, through which a piece of copper wire, C, passes, terminating with a hook or loop. Another piece of wire is suspended from this loop, the end of which is amalgamated. In this arrangement a temporary magnet is made of the soft wire at the bottom of the tube by the voltaic current, and around this the moveable wire, W, revolves, changing its direction by changing the direction of the current.

FIG. 60.

Molecular Changes.—When a bar of soft iron is made into a magnet, and when it is demagnetized, are conditions both of which are attended with molecular motion. The bar, on becoming magnetic, slightly increases in length, and suddenly contracts to its former dimensions when the magnetism ceases.

Ampere's Theory.—If a simple helix, made of thin wire, be freely suspended, and an electric current passed through the helix, it will arrange itself in the magnetic meridian; that is, it will point north and south, and be attracted and repelled by a magnet, just like an ordinary compass needle.

Ampère, who first pointed out the analogy between an ordinary magnet and a helix when conveying an electric current, has deduced a theory

of the connection between magnetism and electricity. He assumes that all bodies which exhibit magnetic polarity derive this polarity from currents of electricity which are perpetually circulating around the particles of which the magnetic bodies are composed. Around each particle an electric current is supposed to be continually circulating, and the direction of these currents is supposed to be uniform, each current circulating in a plane at right angles to the axis of the magnetic power. The resultant of these small currents would be equivalent to that produced by a single current twisting in a spiral direction uniformly around the bar, which would be in the axis of the helix. In an ordinary magnetic needle pointing north and south, the currents would ascend on the western side and descend on the eastern. No proof of these currents can be given, nor of their continuance in permanent magnets. The mutual action between wires which convey currents, and permanent magnets, is easily understood.

Volta-Electric Induction.—A wire under the influence of a voltaic current appears to exert some power on the electrical conditions of the bodies within its sphere, so as to put the electricity of these near bodies in motion, if previously at rest, and if in motion, either to diminish or increase the current force. This effect, called volta-electric induction, is only of a momentary character, and is only evident at the instant of completing or breaking the circuit. Experiment has shown that induced currents possess all the properties of electrical currents. Like them, they give sparks, produce violent shocks, decompose water and salts, and act upon magnetic needles.

Ruhmkorff's Induction Coil.—Secondary currents, which are obtained by magnetic induction, have

a high degree of intensity. If the circuit be broken while the current is passing, a brilliant spark will be observed at the point of interruption. An apparatus for exhibiting these secondary currents has been rendered very efficient by Ruhmkorff. Although there are different forms of this coil, they all consist essentially of two concentric helices of copper wire—the primary or inner coil, consisting of a stouter and shorter wire than the secondary coil, which is made of very long thin wire, insulated with silk; and each layer of coils is separated from the adjacent layers with an insulating varnish of gumlac. A soft iron cylinder is placed in the axis of the coil. In Ruhmkorff's 10-inch coil the inner or primary wire is 0·08854 inch thick and 132 feet long, 300 turns of wire being formed on the instrument. The outer secondary coil is 0·01312 inch thick and 26,246 feet in length, distributed in 25,000 coils. The primary coil is connected with the battery with binding screws. This primary coil is not continuous throughout. It is broken by a small armature of soft iron, to which a plate of platinum is attached on the under surface. As the primary current circulates through the inner or primary coil, the iron cylinder becomes magnetic and attracts the armature. The circuit is now interrupted; the current through the primary coil is immediately stopped; the magnetism of the iron wire ceases; and the armature, or hammer, as it is called, falls, and contact with the battery is immediately renewed; the hammer is again attracted, and immediately falls. Thus the battery acts as a means of making and breaking the contact several hundred times in a minute. A powerful current is induced in the secondary coil by each of the momentary currents in the primary coil.

When an apparatus of this kind is put in motion by a battery of three or four cells, torrents of electricity in a high state of tension are evolved through the secondary coil; and when the two ends of the wire are brought within about one-eighth of an inch together, a succession of bright sparks passes between them.

Fig. 61 represents, more in detail, one of these coils. C is a vertical bobbin, about 12 inches high, standing

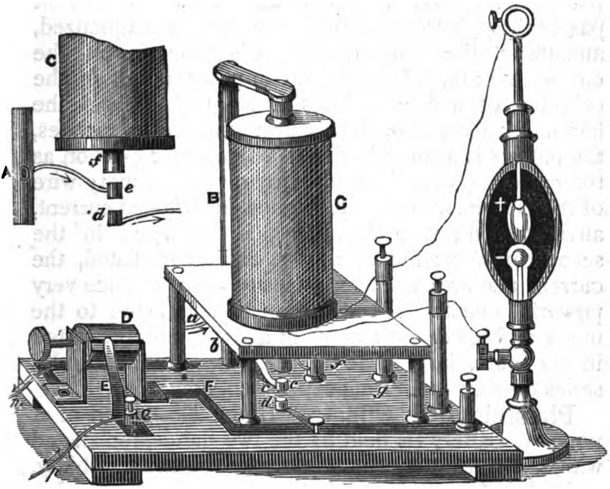


FIG. 61.

on a thick glass plate. The positive pole of the battery is connected with the wire *p* G, and transmits the current by the conductor, E, to the commutator, D; it then passes by F to one of the extremities, *a*, of the primary thick wire of the bobbin; the other end ter-

minates in one of the copper feet, *f*, which support the glass plate, and the current emerging from the bobbin passes to *c*, from which it reaches the iron column, *b* B; it then passes to the oscillating hammer, *e*, which is alternately in and out of contact with the conductor, B. When contact takes place the current passes to D, and returns to the battery by the wire *n*. The oscillations of the hammer *e* are produced by a cylinder of soft iron, *f*, or a bundle of soft iron wire placed in the axis of the bobbin. When the current passes through the thick wire the iron is magnetized, and attracts the hammer, *e*, which is also soft iron; the current is broken, because it can pass through *d*; the cylinder of soft iron loses it magnetism, and the hammer *e* again falls. The current then recommences, the piece *e* is again raised, and so on, in proportion as the current passes intermittently on the primary wire of the bobbin, at each interruption, an induced current, alternately direct and inverse, is produced in the secondary wire; but as this is entirely insulated, the current acquires such an intensity as to produce very powerful effects. If the current be conducted to the upper and lower extremities of a globe, as represented in the figure, the electric light may be exhibited, and a series of other interesting experiments on light.

Physiological Effects.—If the electrodes of a powerful battery be held by the two hands, moistened with salt and water, which increases the conductibility, a shock is felt similar to that produced by the Leyden jar. The violence of the shock is in proportion to the number of elements employed. With a Bunsen or Grove's battery, with 50 couples, the shock is very powerful; with 200 couples it is unbearable, and even dangerous. The human body is a bad conductor. The shock produced by the Leyden jar is due to the

recomposition of the two electricities. With the Leyden jar the shock and the discharge are instantaneous. In the case of a battery the shocks rapidly succeed each other, because the battery after each discharge is immediately recharged. The action of a voltaic current on animals varies with its direction. If a current be sent through the ramifications of the nerves, a muscular contraction is experienced at the commencement, and a painful sensation when it ceases; but if the current be transmitted in the opposite direction, a sensation is produced as long as it continues, and a contraction of the muscles at the moment of interruption. These effects, however, are only produced by feeble currents. With intense currents the contractions and painful effects (no matter in what direction they may be transmitted) occur on closing or breaking the current. By powerful currents rabbits which have been suffocated for half an hour have been restored to life. All the vital actions, some time after death, may be reproduced in dead animals, but they are only of a temporary character, and cease with the transmission of the current.

Electric Telegraph.—The telegraph may be regarded as made up of three parts, viz.:—1. A battery, or some source of electric power; 2. A line for transmitting this power; and 3. An indicator for exhibiting the signals.

The battery may be of any kind; but the form commonly in use in this country for the purpose consists of a series of plates of copper and amalgamated zinc, arranged in wooden troughs, divided into compartments, and coated inside with shellac. After the plates are introduced, the cells are filled with silver sand, and moistened with dilute sulphuric acid.

The conducting wire is made of galvanized iron,

about one-third of an inch thick, and supported on wooden posts. At the upper ends of these posts, short porcelain or glass tubes project, through which the wire passes. If a message has to be sent from London to Liverpool, a continuous insulated conducting wire must extend between the battery in London and the battery in Liverpool, and there must also be a continuous conducting communication between Liverpool and London

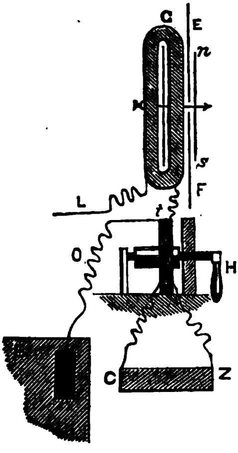


FIG. 62.

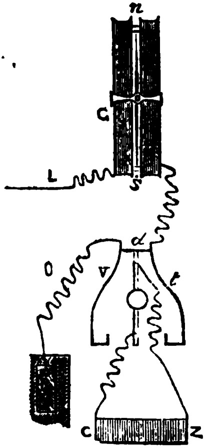


FIG. 63.

to complete the circuit. This return conductor may be another wire going from Liverpool to London, and insulated from the first wire by being suspended through porcelain or glass tubes, on the same posts, a sufficient distance from each other. It was discovered by Steinheil that we may dispense with the second wire, and that the earth may be employed as the con-

ductor for completing the circuit, or return communication, between the two distant stations. The possibility of doing this arises from the law of conduction in solids, viz., that the conducting power increases in proportion to the area of the section of the conductor. In practice all that is necessary to take advantage of the conducting power of the earth is to lead the return wire from the coil to the earth-plate.

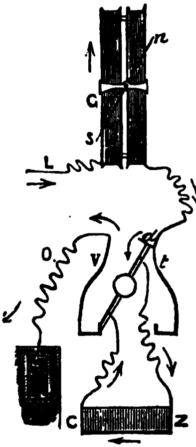


FIG. 64.

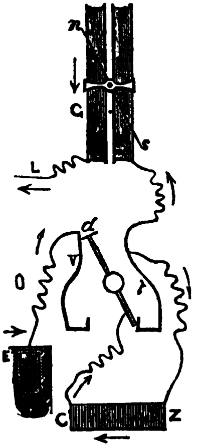


FIG. 65.

The arrangement by which the signals are shown is simply a galvanometer, in which two needles are hung vertically. A section of this part of the apparatus is shown in *Fig.* 62. E F is the dial plate in section, and *n s* is the indicating needle in front. Behind this, in the coil G, is another needle reversed; that is, the north pole points downwards. The deflections of the needle,

n s, are limited by little ivory studs in the dial-plate. L and O are the wires which connect the distant station; C Z is the battery; H is the handle by which the instrument is worked, and P the earth-plate.

Fig. 63 is a back view of the instrument when at rest. A current sent from a distant battery enters the galvanometer by the wire L, passes round the coil, deflects the needle, and escapes by the right-hand wire, which is connected with a steel spring, *t*; it then passes across the metallic bar, *d*, into a similar spring on the left, V; and the circuit is completed by the wire, O, which is attached to the earth-plate, P; the earth

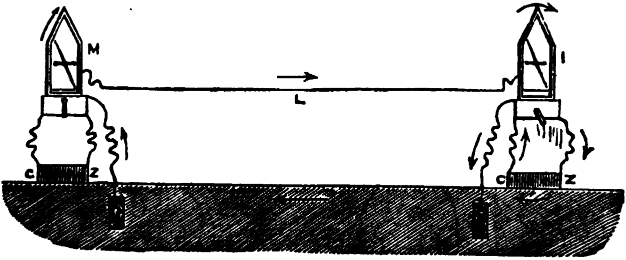


FIG. 66.

acting as the return wire to the distant battery. The battery, C Z, during this operation, is inactive, because the wires, although connected with the brass ends of the vertical piece, are insulated by a circular piece of ivory in the centre. No current can flow, because the wire proceeding from the end of the battery at C is entirely insulated.

When a signal has to be forwarded to a distant station, the handle, H (*Fig.* 62), is moved either to the right or left. In *Fig.* 64 it is represented as moved to the left. The cross-piece, *d*, is pressed against one

of the metallic springs, as shown in *Fig.* 64; and by the same movement the lower end of the vertical piece is pressed against V. The current now flows in the direction indicated by the arrows. The current starts from C to the metallic spring, V, and passes from that to the earth-plate, P; it then proceeds to the distant station, where the instrument, as in *Fig.* 62, is ready to receive the signal. The needle is deflected, and the current returns through L to the galvanometer coil, G, deflects the needle, and returns by the wire attached to the spring *t*, and by the cross-piece *d* completes the circuit to Z. By moving the handle H to the right, as in *Fig.* 65, the direction of the current, and, of course, the deflection of the needle, will be reversed. As soon as the signalling is finished, the cross-piece is restored to the position shown in *Fig.* 63, and the instrument is again ready for receiving signals.

By a little reflection it will be seen that the same motion of the needle is produced at the same instant, both at the sending and receiving station, so that the operator sees on his own instrument the same deflections as are taking place at a distant station, and all the galvanometers connected with the same wire will be similarly deflected (*Fig.* 66).

By an arrangement between the two operators a number of definite movements may be decided upon, which shall indicate letters. Two deflections of the needle to right may be A; three in the same direction, B; four, C; one right and one left, D; and so through the alphabet.

The instrument just described is called the single needle instrument, but by employing two needles a greater number and variety of signals can be forwarded in less time; but each needle requires a separate con-

ducting wire, while the batteries may remain the same. A little inexpensive apparatus will make the principle of the telegraph easily intelligible to a class.

RÉSUMÉ.

Oersted's Experiment.—An electric current transmitted near to a magnetic needle deflects it from its normal position. The north pole of a magnet is invariably deflected to the left of the current which passes between the needle and the observer, who is to look towards the needle, and imagine the current to enter at his feet and to pass out at his head. The needle, as far as terrestrial magnetism permits, endeavours to take up a position perpendicular to the direction of the current. The deflection of the needle is not affected by the interposition of either good or bad conductors between the needle and the current.

The Multiplier.—Currents of electricity sent simultaneously in opposite directions, above and below a magnetic needle, deflect it more powerfully than a single current. This is accomplished by a coil of insulated copper wire, bent into an oval shape, in the middle of which the magnetic needle turns, supported either on a point or suspended by a thread. The extremities of the wire terminate in two mercurial cups or binding screws. Such an instrument is a multiplier.

The Astatic Galvanometer.—The delicacy of an ordinary galvanometer is greatly increased by employing two needles attached together, one above the other, in a parallel direction with their poles, in opposite directions. The lower needle is surrounded by a coil of insulated copper wire. By this arrangement of the needles the directive power of the earth is nearly neutralized, and needles with this arrangement are

said to be *astatic*. The astatic galvanometer, when carefully adjusted, not only shows the existence of a voltaic current, but also its force, which is indicated by the deviation of the needle over a graduated circle.

Conducting Wire.—If the plates of a voltaic couple be connected by means of a fine wire, it can be easily shown that the conducting wire is in a state of activity very different to its ordinary condition. It will be found to be heated along its entire length; and if the wire be very much reduced, and the size of the plates enlarged, the wire will become ignited, or even fused at its finest part. The heat generated will be in proportion to the resistance of the current and the size rather than the number of plates.

Electro-Magnets. — Every metallic conductor, so long as an electric current flows through it, attracts iron filings in the same manner as the poles of an ordinary magnet; and this attraction will not be exerted at particular points, like ordinary magnets, but throughout its entire length. A thin copper wire connected with the poles of a Daniel's or Bunsen's battery will attract iron filings so as to be completely covered; and so long as the voltaic action is continued these filings will be attracted: break the connection and they instantly fall. Small pieces of steel or iron, attracted by the connecting wire, will arrange themselves at right angles to the current and become magnetic, and that end which is to the left of the current will be the north pole. Soft iron retains its magnetic power only so long as the current circulates. Hardened steel retains the magnetism for a much longer time. Soft iron bars bent into the form of a horseshoe, around which an insulated copper wire runs, in the form of a helix, to conduct the current, become

electro-magnets, very far exceeding in suspensive power all other kinds of natural or artificial magnets. Both bar and horse-shoe magnets acquire, at their extremities, the same polarity which the ends of the helix possess. The north pole will always be to the left of the direction of the current. If the direction of the current be changed, the poles of the magnet will be changed.

Volta-Electric Induction.—Voltaic electricity acts on conductors within the sphere of its influence by exciting other currents, and the currents thus generated are said to be induced or secondary. The induced current, formed by bringing a conductor near to a primary current, has an opposite direction. The intensity of these currents is greatly increased by coiling the wires into a spiral form. It is on this principle that induction coils are constructed.

The electric telegraph consists essentially of three parts—1st, a battery to produce the current; 2nd, a circuit, consisting of a metallic communication between two places; 3rd, an indicator. The battery usually consists of a trough divided into compartments, in each of which is an amalgamated zinc plate and a copper plate. The compartments are filled with sand, moistened with sulphuric acid. The connection between the two stations is usually made with a galvanized iron wire, passing through glass or porcelain supports, which are fastened on the posts. In towns, wires insulated with gutta percha are employed, and placed underground.

The place which sends the message is connected with the wire from the positive pole of the battery. The current passes along the line to the receiving station, deflects the needle, and if there were a return wire it would come back to the negative pole of the

battery. Instead of a return wire, the end of the wire at one station, and the negative pole of the battery at the other, are connected with large copper plates, and buried some depth in the earth; the earth acting as the return wire.

EXAMINATIONS

FOR

TEACHERS' CERTIFICATES, NOVEMBER, 1863.

Group III., Subject I.—ACOUSTICS, LIGHT, AND HEAT.

(*The andidate is to confine himself to nine of these questions.*)

1. What is the property which determines the velocity of sound through any medium? On what does the intensity of sound depend? How are both velocity and intensity affected when we ascend from the sea level to a great height in the atmosphere? (9.)

2. How would you explain to a boy the action of a common flute; the use of the holes,—of that to which the lips are applied, as well as those which are covered by the fingers,—and the precise state of the air within the flute when any particular fundamental note is sounded? (11.)

3. Two candles with flames of different brightness are placed in front of a white wall or screen, and an upright rod is held at an equal distance from both candles; will the shadows of the rod cast upon the screen be of the same depth? if not, how would you make them so? and how would you determine from your experiment, and express in numbers, the relative brightness of the two flames? (11.)

4. A stick 6 feet long is set upright in water, the length of the stick above the surface of the water

being exactly 3 feet; but to the eye the length of the stick under the water appears decidedly less than 3 feet. How would you explain to a boy that this must necessarily be the case, or, in other words, that water looked into vertically must appear shallower than it really is? (12.)

5. You look at the sun through a certain glass, and it appears of a pure green; looked at through another glass it appears of a pure red. How are such changes of colour possible to the sun? What will be the effect if you look through both the green and the red glasses together? Suppose both glasses pounded to a fine powder, what would be the colour of that powder? Please to give the reasons for your answer. (12.)

6. Standing on the sandy beach of Normandy, I saw a high and distant rock with its inverted image underneath, as if the rock had been surrounded by calm water, from which the image was reflected; the rock, however, was surrounded at the time by level sand, heated by the sun. How was the image formed? (12.)

7. Dry transparent ice when pounded appears like snow; transparent rock salt when pounded appears like common table salt; transparent glass when pounded produces a white powder. All these powders are practically opaque. How is it possible for a transparent substance thus to change its nature? I have recently observed that certain alcoholic liquids have the power of rendering opaque white letter-paper almost perfectly transparent: explain the effect. (12.)

8. Give a drawing of the human eye, and name its various parts. Explain the use of spectacles as applied to long sight and short sight respectively. (11.)

9. Explain, and clearly illustrate, the formation of the primary and secondary rainbows. (I shall require

great clearness in the answer to this question, so that if not quite master of the subject it would be better for the candidate not to attempt it; a good answer, however, will obtain a high number.)

10. A bombshell is accurately filled with water at a temperature of 50° Fahr.; the shell is closed by a rigid plug, and exposed to a freezing temperature: it finally bursts. Explain the entire series of changes which the water has passed through from the time of its introduction into the shell till the time of rupture. At the time of rupture what change as to temperature occurred in the mass within the shell? (12.)

11. When the windows of a room are opened in which many people have assembled and many lights are burning, on a cold night, a dimness is seen to pervade the atmosphere of the room. Whence does this arise? Explain the formation of snow from its origin to its end. (11.)

12. A sheet of metal placed upon a sloping surface will gradually creep down it, not by sliding, but in consequence of changes of temperature. How do you suppose these changes to act? (10.)

13. A porous earthenware vessel intended to hold water for drinking is now before me, and I notice a kind of dewiness on its external surface. It was filled an hour ago, and at the same time a second unporous vessel was filled with the same water. The water in the two vessels is not now at the same temperature: state the reason, and explain in connection with it why the blood of an individual at the equator is scarcely sensibly hotter than that of an individual in the polar regions. (11.)

14. If you cover a polished silver teapot closely with flannel the hot liquid will cool more rapidly than when the pot is naked. If, however, you surround the tea-

pot with a loosely fitting bag of the same material the cooling is retarded :—explain all this. (12.)

15. What is meant by the mechanical equivalent of heat, and how has this equivalent been determined? (14.)

EXAMINATIONS

FOR

TEACHERS' CERTIFICATES, NOVEMBER, 1863.

Group III., Subject II.—MAGNETISM AND ELECTRICITY.

(*The candidate is to confine himself to nine of these questions.*)

1. Give one or two good illustrations of the phenomena to which the term *magnetic induction* is applied, and add an explanation of the phenomena. (8.)

2. Describe the inductive action of the earth upon a bar of soft iron, stating the best position in which to hold the bar, the manner in which it is magnetized, and the means you would adopt to render the magnetism permanent. (10.)

3. A horse-shoe magnet is laid flat upon a table, and a sheet of paper is placed upon it, and over the paper iron filings are scattered ; show by a sketch the manner in which they will arrange themselves, and give an explanation of the phenomenon. (14.)

4. What is the origin of the terms *resinous* and *vitreous* as applied to electricity? Show the impropriety

of these terms. You cannot obtain electricity by friction on the surface of a metal as you can on the surface of a resinous or vitreous body: why? (10.)

5. You are furnished with two sticks of sealing wax, two bits of glass tubing, a bit of flannel, and a bit of silk: explain to me how you would by these means demonstrate the fundamental laws of electric attraction and repulsion. (10.)

6. I wish you to devise and describe some extremely simple way of illustrating and explaining the action of the Leyden jar, without making use of the jar itself. (12.)

7. Give a theory of thunder and lightning, and explain the action of a lightning conductor on an electrified cloud. (11.)

8. Why is it that trees and walls are shivered and animals killed by a lightning discharge, when metal railings and bronze statues of men and animals are quite unharmed by it? State what you know regarding the law which rules the development of heat by electricity. (11.)

9. Show by a sketch the manner in which you would illustrate the phenomenon of the *return shock* upon a dead frog. (13.)

10. Describe an electric machine; and explain the use of the points which are usually attached to the prime conductor. (10.)

11. Describe some very simple experimental arrangements by which you can obtain a voltaic current. What proof can you adduce of the existence of the current after you have obtained it? (8.)

12. How would you experimentally illustrate the decomposition of water by an electric current? Show by a sketch the places at which the components of the water would be liberated. (10.)

13. A tangent compass and a cell in which water may be decomposed are introduced into the circuit of a voltaic battery: how is the action of the current on the needle of the compass related to the chemical action in the decomposing cell? (13.)

14. Describe some arrangement by which a long spiral through which an electric current flows may be suspended horizontally, so that it may move freely in the plane of the horizon. Describe the action of the earth upon such a spiral. (14.)

15. By the introduction of a steel magnet into a coil of copper wire I obtain an electric current: describe the character of this current, and state its direction with reference to the end of the magnet introduced into the coil. (14.)

EXAMINATION QUESTIONS

FOR

SCIENCE SCHOOLS AND CLASSES, MAY, 1864.

Group III., Subject I.—ACOUSTICS, LIGHT, AND HEAT.

GENERAL INSTRUCTIONS.

Three hours are allowed for this paper.

You are only permitted to attempt ten questions.

You may select any ten of the questions in the paper.

The value attached to the correct answer of each question is marked against it.

N.B.—A full and exact answer will in all cases gain more marks than an inexact or incomplete one; though in the former case the question may be the more easy of the two and have less value attached to it.

---

1. A cannon ball fired at a target 4,000 yards distant moves at the rate of 1,600 feet a second; will the ball reach the target before or after the sound of the explosion? What is the difference of the times of their arrival? (6.)

2. Does the motion of the sound resemble that of the cannon ball referred to in the last question? If not, state clearly the difference between the two kinds of motion. (8.)

3. When a prolonged note is sung by a person at a distance, how is the air between you and the singer affected, both as regards its density and as regards its temperature? What change occurs in the state of the air when the pitch of the note is altered? (20.)

4. State the relative lengths of the strings which produce the notes of the gamut, and calculate the relative lengths of the sonorous waves which these strings produce. (16.)

5. A sunbeam enters a room through an aperture in the window shutter; you receive the ray upon a mirror, and reflect it so as to make the angle enclosed by the direct and reflected rays 100 degrees. What is the inclination of the two rays to the surface of the mirror? (8.)

6. I hold a candle six inches from a looking-glass, and with my eye at the same distance from the glass, and at a foot distance from the candle, I observe its

image. This image is not single, but consists of a series of images which grow gradually fainter. How are they produced? (18.)

7. The second of the images here referred to is much the brightest; but when I bring both the candle and my eye quite close to the mirror the first image becomes almost as bright as the second. Explain this. (18.)

8. I place a spectacle-glass used by a long-sighted person in front of a candle, and obtain an image of the candle upon a distant screen. Describe this image, and explain how it is produced. (13.)

9. I interpose in the same manner between a screen and a candle a glass used by a short-sighted person; is it possible to obtain an image of the candle? State the grounds on which your answer is founded. (13.)

10. What is meant by the solar spectrum? Describe clearly how such a spectrum may be obtained. (6.)

11. In the window of a druggist's shop I observe two liquids—one intensely red, the other intensely blue. A solar spectrum is cast upon a screen; how will this spectrum be affected when the coloured liquids first referred to are placed in succession in the path of the rays which produce the spectrum? (18.)

12. What is meant by the term "complementary colours"? (8.)

13. Describe some means by which a number of colours may be so mixed together as to produce the impression of colourless white. (18.)

14. Why does the water of a clear river or lake, or even the water in a basin, appear shallower than it really is? (10.)

15. I observe in the window of a philosophical instrument maker an announcement to this effect:—

"Lowest temperature last night, 11° above freezing." What is the full meaning of this announcement? Add to your answer a description of the mercurial thermometer. (8.)

16. On the summit of Monte Rosa, on the 9th of August, 1858, water boiled at a temperature of 184°·92 Fahrenheit. How many degrees is this below the boiling point at the sea level, and what is the cause of the difference? (13.)

17. In a hole in a block of ice I place a thermometer, which then shows a temperature of 20° Fahrenheit. The ice is then placed in a vessel to which heat is applied, until the ice melts and the water boils until it is all converted into steam. What are the indications of the thermometer from the beginning to the end of the process? (20.)

18. I heat a boiler to which a narrow pipe is attached until steam issues violently from the pipe. I then notice that the space for about two inches from the end of the pipe is quite transparent, but that beyond this point the course of the steam is marked by a cloud in the air. I cause this cloud to pass through a flame; it disappears, and all is again transparent. Explain the whole process. (22.)

19. The specific heat of iron is 0·1. What is the meaning of this statement? (12.)

20. The latent heat of water is 142° Fahrenheit. The latent heat of steam is 967° Fahrenheit. What is the exact meaning of these statements? (16.)

21. The specific heat of air is $\frac{1}{4}$; the specific gravity of air $\frac{1}{770}$: a cubic foot of water loses one degree in temperature. How many cubic feet of air would the amount of heat thus lost raise one degree? (24.)

22. When you look at objects through the air above

a heated surface they appear to tremble and quiver. What is the cause of this? (22.)

23. What is meant by *total reflexion?* Illustrate your answer by an example. (15.)

24. Why is the sun a deep blood-red when looked at through the smoke of London? I wish you to state here how the solar light is acted on by the smoke so as to produce the red colour. (28.)

EXAMINATION QUESTIONS

FOR

SCIENCE SCHOOLS AND CLASSES, MAY, 1864.

Group III., Subject II.—MAGNETISM AND ELECTRICITY.

GENERAL INSTRUCTIONS.

Three hours are allowed for this paper.

You are only permitted to attempt ten questions.

You may select any ten of the questions in the paper.

The value attached to the correct answer of each question is marked against it.

N.B.—A full and exact answer will in all cases gain more marks than an inexact or incomplete one; though in the former case the question may be the more easy of the two and have less value attached to it.

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1. State what you know regarding the constitution and the action of a natural magnet. (8.)

2. How is the magnetic condition excited in steel? What is the difference between iron and steel as regards their magnetic properties? (6.)

3. The marked end of a magnet is drawn towards the north magnetic pole of the earth; why does not the magnet move towards the north pole when it is rendered free to move by being set afloat on water? What is the meaning of the earth's magnetic pole, as distinguished from the geographical pole? (10.)

4. I wish to magnetize a steel bar by the magnetism of the earth; in what direction must I hold the bar, and how must I deal with it to obtain the strongest possible magnetism? (8.)

5. Give a full explanation of the magnetic curves in which iron filings arrange themselves round a magnet; let your explanation be accompanied by a sketch of the curves. (20.)

6. When you rub glass with silk what is the electric state of the rubber? Can you excite the one electricity without the other? (6.)

7. When I speak of the one electricity and the other in the last question, what do I mean? (16.)

8. I pass a vulcanized india-rubber comb through my hair and find it electrified: you are required to determine the quality of the electricity; how will you do it? (10.)

9. State what you know regarding electric induction. (16.)

10. Explain the action of the condenser by reference to electric induction. (20.)

11. How do you apply the laws of induction to the explanation of the electrophorus? (20.)

12. How do you apply the laws of induction to the explanation of the Leyden jar? (20.)

13. State the theory of lightning conductors. (10.)

14. You are required to electrify a brass rod by the friction of flannel; how will you do it? (16.)

15. What is the meaning of the term "voltaic electricity"? Describe a simple means of obtaining a voltaic current. (8.)

16. A voltaic current crosses one's magnetic needle from east to west; what is the effect? The same current passes over the needle from south to north; what is the effect? (20.)

17. A current passes round a bar of soft iron; what is the effect? The direction of the current is reversed; what is the consequence? What do you mean by the direction of a voltaic current? (12.)

18. Give a full description of a cell of Grove's nitric acid battery, and state the chemical actions that occur within the cell. (12.)

19. What is meant by electric polarization? How does it affect the current when a single liquid and two metals are employed? (22.)

20. A great external resistance is to be overcome; how must I arrange the cells of my battery to overcome it? The external resistance is very small, but I want to obtain a copious current; how must I connect my cells? Give the reasons for your answer. (22.)

21. State what you know regarding the chemical action of the voltaic current in the external portion of the circuit. (15.)

22. Give a description of the astatic needle. Such a needle sets at right angles to the magnetic meridian: explain this. (24.)

23. On what does the development of heat by a

voltaic current depend? State the law which regulates this development. (15.)

24. Describe the tangent compass, and state how it must be arranged to determine the strength of an electric current. Prove that the strength of the current is proportional to the tangent of the deflection. (24.)

EXAMINATION

FOR

SCIENCE CERTIFICATES, NOVEMBER, 1864.

Group III., Subject I.—ACOUSTICS, LIGHT, AND HEAT.

(*Nine questions only to be taken. The value of the questions is equal.*)

1. The windows of Erith church were all pushed *inwards* by the recent explosion of a powder magazine; those behind, as well as those facing the spot where the explosion occurred. Explain this.

2. Describe and explain the Eolian harp.

3. A person standing on the platform of a railway station sounds a musical note of a certain definite pitch. Will that note be of the same pitch to a passenger rapidly approaching the station in an express train? Will it be the same after the train has rushed

past the station? If not, how is the note affected by the train's motion?

4. An upright iron railing has its shadow cast on the pavement by two different lamps; the shadows cross each other, being darkest at their places of intersection: why? At a distance of 12 yards from the one lamp, and of $7\frac{1}{2}$ yards from the other, the separate shadows of the rails are equally dark: what are the relative intensities of the two lights?

5. Prove that the image of an object formed by a concave mirror between the principal focus and the surface of the mirror must be diminished and inverted.

6. Does a sportsman on a river's bank appear in his natural size and proportions to a fish swimming in the river? If not, how is his appearance affected?

7. State the particulars in which the phenomena of light are similar to those of sound, and also the particulars in which they differ.

8. State the particulars in which the phenomena of radiant heat are similar to those of light, and also the particulars in which they differ.

9. Describe and explain the camera ordinarily employed by photographers.

10. Give an instance in which imparting heat to a body causes it to contract. Define what is meant by the coefficient of expansion; state the coefficient of expansion of air, and the difference, if any, between it and the coefficients of other gases.

11. What is the meaning of the following two phrases,—"specific heat at constant pressure," and "specific heat at constant volume"? Are both specific heats the same? If not, why do they differ?

12. From what height must a block of ice fall, so

that the quantity of heat generated by its collision with the earth shall be just competent to melt it?

13. Ten pounds of ice at a temperature of 20° Fahr. are heated, melted, and finally converted into vapour. To perform this a certain amount of heat is necessary; how many pounds of water would this heat raise from 50° to 100° Fahr. in temperature? (NOTE.—The specific heat of ice is 0·5.)

14. Describe the Davy lamp, and explain its action.

15. Describe in detail how a solar spectrum may be obtained, and also the manner in which the heat of the spectrum is distributed.

EXAMINATION

FOR

SCIENCE CERTIFICATES, NOVEMBER, 1864.

Group III., Subject II.—MAGNETISM AND ELECTRICITY.

(*Nine questions only to be taken. The value of the questions is equal.*)

1. State fully and clearly what you understand by the term "magnetic polarity."

2. Describe the experiments which cause you to conclude that the molecules of a magnet are them-

selves magnets. Does the centre, or equator, of a bar magnet exert any action on the end of a magnetic needle brought near it? If so, what action?

3. Give a sketch of the phenomena of terrestrial magnetism.

4. State some broad points of distinction between the phenomena of magnets and of electrified bodies.

5. I wish to show a class that the electricity of the rubber and that of the body rubbed, in the case of the electric machine, are of opposite qualities. How am I to do it?

6. Describe one or two experiments by which you would illustrate before your class the fundamental phenomena of electric induction.

7. The term induction is applied to certain effects of static electricity, and it is also applied to electric currents. Explain the term in both cases.

8. Describe the fundamental experiments which prove the possibility of transmitting intelligence of the action of an electric current on a magnetic needle.

9. Describe some experimental means of determining the strength and the direction of a voltaic current.

10. Currents of various strengths are sent round the same bar of soft iron; how would you determine the strength of the magnetism, excited in the bar, of each current?

11. Describe the electrophorus, and give the theory of its action.

12. Describe the process of electro-plating, and illustrate the process by an example fully worked out.

13. Describe the electric machine, and the Leyden jar. Show, by a sketch, how you would proceed in charging the jar by the machine.

14. You are furnished with wires of two different metals, and required to determine the relative conductivity of the two metals for electricity: how would you proceed?

15. Describe the batteries of Grove, Bunsen, and Daniel; and state the chemical effects which occur in each when the current circulates.

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